1925

# The design of a general-purpose tractor

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# THE DESIGN OF
# A GENERAL-PURPOSE TRACTOR

BY

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A Thesis submitted to the Graduate Faculty

for the Degree of

MASTER OF SCIENCE

Major subject Agricultural Engineering.

Approved

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In charge of Major work.

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Head of Major Department.

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Dean of Graduate College.

Iowa State College

1925

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## ACKNOWLEDGEMENTS

The writer wishes to express his sincere appreciation to Prof. J. B. Davidson under whose supervision and guidance the project has been conducted and who has contributed some of the main ideas upon which this work has been built; to Mr. E. V. Collins for the many valuable ideas contributed and constructive criticism offered, and to Prof. P. W. Eells for valuable suggestions which he has given.

## INTRODUCTION.

Cheaper power is one of the greatest needs of agriculture to-day. Although power represents about 20% of the cost of production of farm crops, it receives but little attention from economists and others who are vitally interested in lowering the cost of production.

The farmer has two sources of power for tractive work, animal and mechanical. Recent investigations indicate that mechanical power, where used, costs less than animal power, yet it is shown that about 90% of the work is done by the more costly source. It is obvious from this that there is something wrong with the use of farm power in the United States, when viewed from an economic standpoint; either the farmer is following unsound principles, or the manufacturer of farm equipment is not supplying his needs.

The use of more mechanical power would appear to be the natural and logical solution for this problem, but with the tractor in its present stage of development it is doubtful if more mechanical power can be used to any great advantage. The tractor has not as yet reached the stage where it can be used for all purposes to the same extent as animal power. Herein lies the great drawback of the tractor. It is only by making the tractor more versatile that we can hope to bring it into more extensive use economically. As long as the corn-belt farmer must keep his horses to cultivate his corn during the hottest day of summer while the tractor which plowed and prepared the land stands idle, there is going to be little gained by using more tractors.

The writer believes that the general-purpose tractor will open the gateway to cheaper power. It is the object of this thesis, first, to state the farm power problem as it exists to-day, and secondly, to take steps towards its solution. The first part will be an economic study, based upon the most reliable data available. It is not hoped to present a complete and detailed plan of a general-purpose tractor in this treatise, but a careful study of the requirements of such a machine will be made, and as far as possible these requirements will be incorporated into the proposed general-purpose tractor.

# SECTION I

## THE FARM POWER SITUATION

Before the farm power requirements can be dealt with intelligently it is necessary that all phases of farm power be thoroughly understood. The purpose of this chapter is to present an economic study of the farm power situation as it exists in the United States to-day.

### 1. Sources of Farm Power.

The sources of farm power may be classified into two main groups, animal and mechanical. In the early development of this country the former was used exclusively. It was not until after 1870 that mechanical power came into use in agriculture. Plate I taken from the National Farm Power Survey* of the United States Department of Agriculture shows the steady increase in the use of mechanical power since that time. This plate also shows the amount of each source of mechanical power;- steam and gas engines, windmills and electrical machines used in agriculture.

Table 1, also from the National Farm Power Survey, gives the total primary horse-power used in agriculture in the United States in 1923, which amounts to over 49,000,000 horsepower. Of this amount nearly 22,000,000, or 44%, consists of animal power while the remainder is made up of the various

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* Paper prepared by Mr. C. D. Kinsman, Senior Agricultural Engineer of the U. S. D. A. and read by him at the annual meeting of the American Society of Agricultural Engineers at Lincoln, Nebraska, in June, 1924.

TABLE I.

APPROXIMATE PRIMARY HORSE POWER AND HORSE POWER HOURS UTILIZED ON FARMS IN THE UNITED STATES ANNUALLY.
From the National Farm Power Survey, U. S. D. A.

| Kind of power | Total Units or Installations. | Total Primary Horse Power | | Average H. P. Hours per Primary H. P. | Total H. P. Hrs. Dev'd Annually. | |
|---|---|---|---|---|---|---|
| Work Animals | 21,868,000 | 21,660,000 | 44.1% | 447 | 9,690,000,000 | 61.4% |
| Gas Tractors (a) Draw Bar | 400,000 | 4,000,000 | | 225 | 900,000,000 | 5.7% |
| (b) Belt | | 8,000,000 | 16.3% | 79 | 632,000,000 | 4.0% |
| Steam Tractor | 50,000 | 2,500,000 | 5.1% | 400 | 1,000,000,000 | 6.3% |
| Trucks | 356,000 | 7,120,000 | 14.5% | 80 | 570,000,000 | 3.6% |
| Stationary En's: (a) Large | 20,000 | 500,000 | 1.0% | 892 | 446,000,000 | 2.8% |
| (b) Small | 2,480,000 | 6,820,000 | 13.8% | 820 | 1,500,000,000 | 9.5% |
| Windmills | 1,000,000 | 500,000 | 1.0% | 400 | 200,000,000 | 1.3% |
| Electricity (a) Indi v Pla: Plants | 300,000 | 900,000 | 1.8% | 167 | 150,000,000 | 1.0% |
| (b) Cen.Sta's: Small | 170,000 | 680,000 | 1.4% | 143 | 100,000,000 | .6% |
| (c) Cen.Sta's: Large | 20,000 | 500,000 | 1.0% | 1200 | 600,000,000 | 3.8% |
| TOTAL | 26,664,000 | 49,180,000 | 100.0% | 320 (av: | 15,788,000,000 | 100.0% |

Plate I Total primary horsepower on farms, 1850 to 1924.

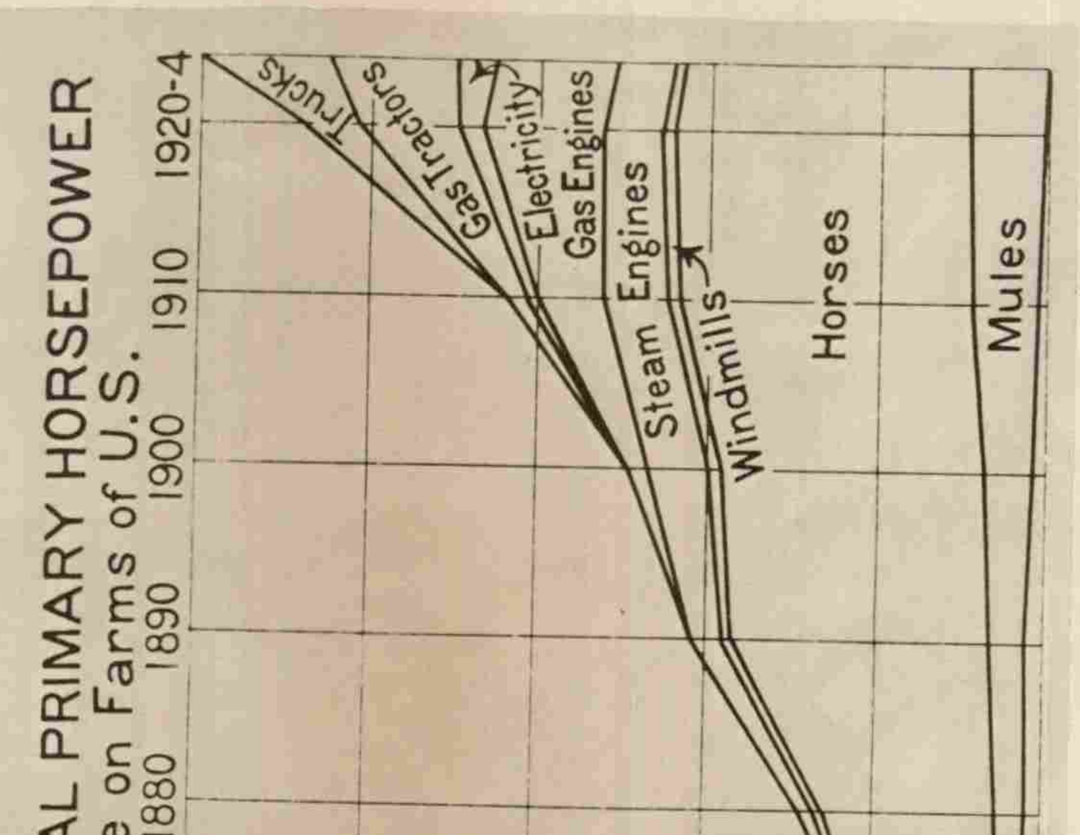



Plate I

kinds of mechanical power as shown in the table.

## II. Power Developed by Each Source.

Work animals supply 61.4% of the power used in agriculture, as shown by Table 1, although the primary horsepower represented by that source is only 44.1%. This is due to the fact that the animal works a greater number of hours per year than does the average unit of mechanical power. The gas tractors supply 9.7%, and small stationary engines 9.5% of the total power used. These are the largest individual items outside of animal power. The table shows clearly how large is the amount of animal power used in agriculture as compared with that supplied by any other source.

## III. Uses of Farm Power.

The use of power on farms may be divided into two main classes, belt work and tractive work. The latter may again be subdivided into hauling and field work.

Table II shows the amount of power used for the various farm operations.

### 1. Field Work.

Approximately half the power used on farms is used for field work. Plowing and listing is the largest single item, comprising almost 40% of the total. Cultivating and fitting ground are the two next items in importance, each taking 13.2% of the total power used for field work. Other items of field

TABLE II

POWER USED FOR DIFFERENT FARM OPERATIONS.

Compiled from National Farm Power Survey.

| Operation | H. P. Hours used Annually (in millions). | | | |
|---|---|---|---|---|
| **1. Field Work.** | | | | |
| Plowing and listing | 2,500 | 32.9% | | |
| Fitting ground | 1,000 | 13.2% | | |
| Planting and seeding | 400 | 5.3% | | |
| Cultivating | 1,000 | 13.2% | | |
| Harvesting | 800 | 10.2% | | |
| Haying | 900 | 11.9% | | |
| Miscellaneous | 1,010 | 13.3% | | |
| Total Field Work | | 100.0% | 7,610 | 48% |
| **2. Belt Work.** | | | | |
| Threshing | 1,200 | 25.9% | | |
| Pumping | 1,600 | 34.5% | | |
| Cutting ensilage | 50 | 1.1% | | |
| Shelling corn | 80 | 1.7% | | |
| Shredding corn | 100 | 2.2% | | |
| Baling hay | 100 | 2.2% | | |
| Grinding feed | 200 | 4.3% | | |
| Operating electric light plants | 150 | 3.3% | | |
| Sawing wood and lumber | 100 | 2.2% | | |
| Miscellaneous | 1,048 | 22.6% | | |
| Total Belt Work | | 100.0% | 4,628 | 29% |

3. Hauling.

| | | | | |
|---|---|---|---|---|
| Farm hauling | 1,200 | 34.% | | |
| Road hauling | 2,350 | 66.% | | |
| Total Hauling | | 100.% | 3,560 | 23% |
| TOTAL H. P. HOURS FOR ALL OPERATIONS | | | 15,788 | 100% |

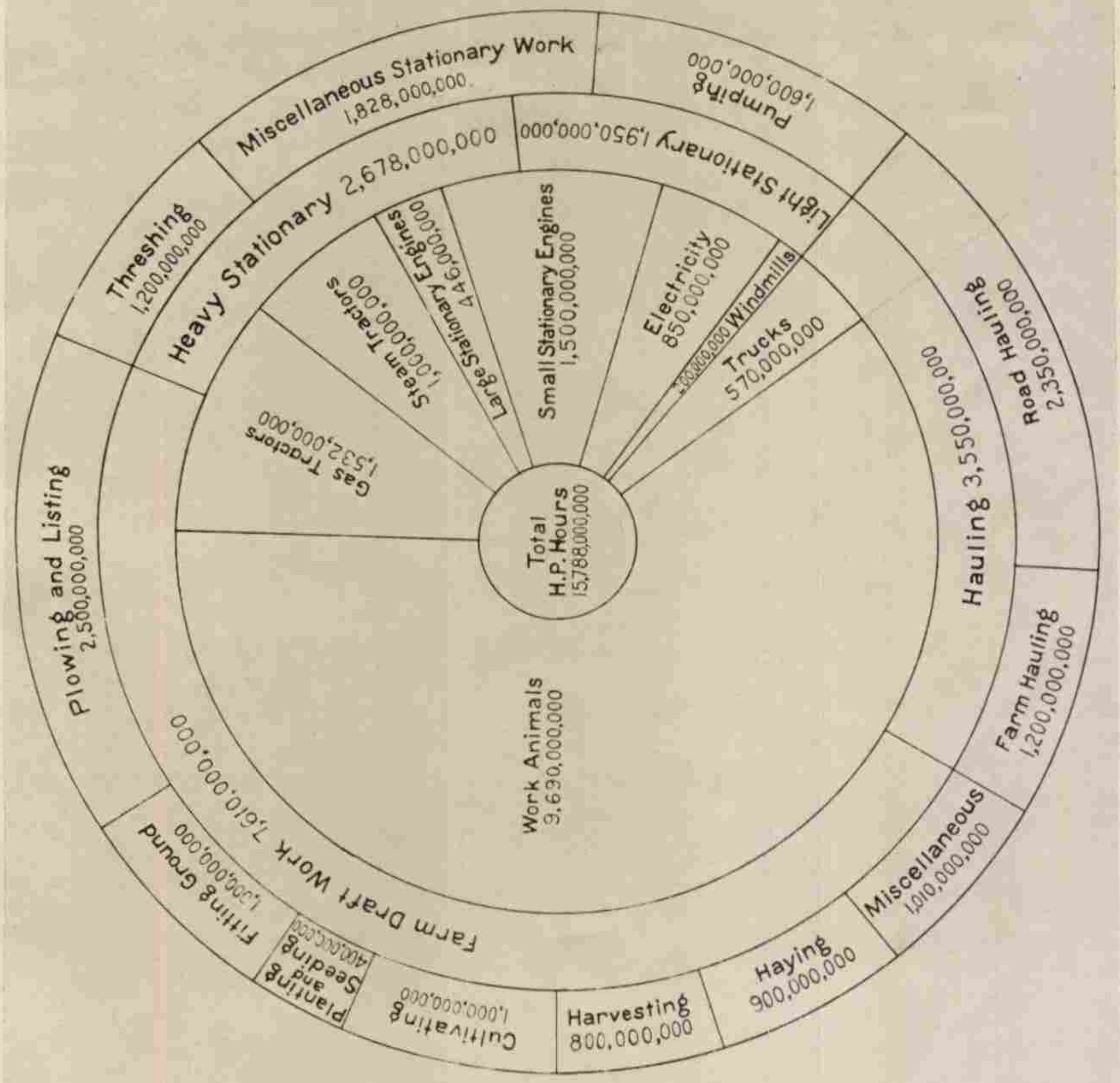

Total
H.P. Hours
15,788,000,000
Work Animals
9,630,000,000
Gas Tractors
1,532,000,000
Steam Tractors
1,000,000,000
Large Stationary Engines
446,000,000
Small Stationary Engines
1,500,000,000
Electricity
850,000,000
100,000,000 Windmills
Trucks
570,000,000
Heavy Stationary 2,678,000,000
Light Stationary 1,950,000,000
Hauling 3,550,000,000
Farm Draft Work 7,610,000,000
Miscellaneous Stationary Work
1,828,000,000
Pumping
1,600,000,000
Threshing
1,200,000,000
Road Hauling
2,350,000,000
Farm Hauling
1,200,000,000
Miscellaneous
1,010,000,000
Haying
900,000,000
Harvesting
800,000,000
Cultivating
1,000,000,000
Planting and Seeding
400,000,000
Fitting Ground
1,000,000,000
Plowing and Listing
2,500,000,000

Plate II

work range as follows: haying 11.9%; harvesting 10.2%; and planting and seeding, only 5.3%.

2. Belt Work.

Pumping constitutes about one-third of all belt work on farms, Threshing is the only other large item, amounting to about 26% of the total. Smaller items of belt work are: cutting ensilage, shelling corn, shredding corn, baling hay, grinding feed, sawing wood and operating electric light plants. All belt work consumes about 29% of the total amount of power used on farms.

3. Hauling.

About 23% of farm power is used for hauling, of which road hauling makes up 66% and farm hauling 34%.

Plate II, taken from the National Farm Power Survey, shows praphically how the total power on farms is utilized, as well as the amount supplied by each source, in 1923.

## IV. Advantages of Each Source.

Before proceeding further with statistical data on farm power, it might be well at this point to discuss in a general way the relative advantages of animal power and mechanical power for different kinds of farm work.

1. Belt Work.

When the stationary engine first came into use to replace the sweep-power and treadmill, which up to that time had been used for threshing and other belt work, its advantages were self-evident and were not seriously disputed. Under those conditions the engine is most efficient, while the horse works under conditions of lowered efficiency. It was not long until the engine entirely replaced animal power, until to-day the sweep power and the treadmill are entirely obsolete. All belt work is therefore strictly classed as mechanical work.

2. Tractive Work.

Although the engine is so far superior to animal power for belt work, when applied to any form of tractive work the comparison is quite different. Here the horse meets the tractor on its own ground, so to speak. The only way that a horse can be made to do work is by pulling a load; it is the natural way for him to do work, and he therefore works at his maximum efficiency in that way. Not so with the engine. It is a well-known fact that the engine loses approximately half of its power in the transmission and drive wheels, so that the power available at the drawbar is only about half of that which the engine can deliver at the belt.

(a) Field work. Through gradual mechanical improvements the tractor has become a very keen competitor of the horse for field work, although by far the larger portion of that work is still done with horses.

(b) Hauling. For short hauls it is generally considered that horse labor can be employed more economically than mechanical power; but among farmers who live far from market, the truck is coming into considerable popularity.

The chief advantages of the two different sources of power for tractive work may be summed up as follows:

3. Advantages of the Horse.

(a) Large overload capacity.

(b) Flexibility of size of units used.

(c) Versatility.

(d) Skilled labor not required.

(e) Intelligence.

(f) Long life.

(g) Self-repair and self-reproduction.

These headings can be explained in turn as follows:

(a) Overload capacity. The normal working load for a horse is about 10% of his weight. It has been shown that a good horse can pull 90% of his weight for a short distance, which is equivalent to a 900% overload. This is much greater than can be achieved with any form of mechanical power. The large overload capacity of the horse is probably one the biggest advantages that it has over the tractor.

(b) Flexibility. The fact that the horse can be used in units of from one to ten, or even more, makes it very convenient to adapt animal power to different machines or to different conditions with the same machine. The user of animal power has therefore a very flexible source of power.

(c) Versatility. The horse can be used for all the different operations on the farm required tractive power, which is not true of the tractor, at least not up to its present stage of development.

(d) No skilled labor required. It is no doubt true that greater skill is required to operate and take care of a tractor than to drive and take care of a team of horses. This may be taken as one advantage of animal power, although men who are mechanically inclined often get along better with a tractor than with horses.

(e) Intelligence. The intelligence of the horse makes it possible to teach him to do certain things without direct guidance. Although in many respects this is an advantage, it renders the animal sensitive to adverse conditions such as flies and heat.

(f) Long life. The useful life of a horse is perhaps twice that of the tractor, at the present stage of its development. With improvement and better care, the life of the tractor is being gradually lengthened, so that it is quite possible that the time will be reached when the difference will not be great.

(g) Self-repair and self-reproduction. The horse as a motor is a remarkable machine. Repair of broken-down tissues is carried on by nature's process, so that outside of being supplied with food and shelter, the machine requires little attention. Nature's own process also takes care of the reproduction and building of this extraordinary machine.

4. Advantages of the Tractor.

(a) Cheaper power.

(b) No rest periods required.

(c) No fuel consumption when idle.

(d) Hot weather is no hindrance.

(e) Less weight per horsepower.

(f) Mechanical power required for belt work.

(g) Less machinery required with tractor.

(a) Mechanical power cheaper. As the matter of cost is of first importance it will be taken up separately. It is sufficient here to say that investigations have shown mechanical power to be considerably cheaper than animal power.

(b) Tractor requires no rest. The amount of work that a horse is able to do in a day is limited; if he is made to work long hours he must travel slower or draw a lighter load. The tractor, however, may be kept at work continuously during the busy season to speed up operations. The advantages gained by having the work done at the right time are often difficult to measure in dollars and cents.

(c) No fuel consumed when idle. When a horse is idle he requires about two-thirds of his full ration. As the horse seldom works more than one-third of the year, the feed bill when he is idle must necessarily be high. On the contrary, the tractor consumes fuel only while actually at work.

(d) Hot weather is no hindrance. A tractor works at its highest efficiency when the temperature of the cooling water is around boiling. For that reason the tractor will be most efficient during the hottest weather. It is during this time that work animals are greatly hindered by the excessive heat, which not only lowers their efficiency but causes sore shoulders and loss of flesh.

(e) Less weight per horsepower. It requires a horse of about 1600 lbs. to develop one horsepower. A tractor of 10 drawbar horsepower weight about 4,000 lbs. or 400 lbs. per drawbar horsepower. The horse therefore weighs four times as much per horsepower as the tractor.

(f) Mechanical power required for belt work. Every farm has a considerable amount of belt work to be done, and as mechanical power is required for this purpose, it is very convenient that the same power unit can also be used for tractive wor, as the two kinds of work do not often require to be done at the same time. As economy in the use of power depends largely upon keeping the power unit busy a large proportion of the time, it is a considerable advantage to be able to use the same source for as many purposes as possible.

(g) Less machinery required. There are two reasons why less machinery is required for use with a tractor than with horses; the first is that the tractor is able to work continuously, requiring no rest periods, and the second is that the tractor may be designed to travel faster than the average horse. The working speed of a horse at field work is about 2½ miles an hour. Many tillage machines can be used efficiently at a higher speed, and the same machine can therefore be made to cover more ground in a day when drawn by a tractor which can be designed to work at any speed consistent with the work being done.

## V. Cost of Farm Power.

The cost of power is of first importance, yet that phase of the problem is the one which is most difficult to deal with in the way of getting reliable data. In this study as many sources of information as possible are being used, with a view of getting more reliable results.

### 1. Total cost per year.

The total cost of farm power in the United States in 1923 was almost three billion dollars. The cost of power obtained from each source during that year is given in Table III. This is based upon the costs as found by Mr. Kinsman. The table will be found on the following page.

A better idea of the magnitude of this item in the cost of production may be obtained by considering the cost per farm and the cost per improved acre. This is given in Table IV, which will also be found on the next page.

### 2. Relation to other items.

The relation between the different items in the cost of growing corn is approximately as follows:-

| | | | |
|---|---|---|---|
| Land | 50% | Labor | 20% |
| Power | 20% | Miscellaneous | 10% |

TABLE III.

Cost of Power in Agriculture, 1923

| Kind of Power | Total H. P. Hrs Dev'pd Annually | Cost per H. P. Hr. | Total Cost |
|---|---|---|---|
| Work Animals | 9,690,000,000 | .24¢ | $2,305,000,000 |
| Gas Tractors: | | | |
| Draw Bar | 900,000,000 | .12½¢ | $ 112,500,000 |
| Belt | 632,000,000 | .06 | 38,000,000 |
| Steam Tractors | 1,000,000,000 | .05 | 50,000,000 |
| Trucks | 570,000,000 | .20 | 104,000,000 |
| St'nry Engines | 1,946,000,000 | .09 | 175,000,000 |
| Windmills | 200,000,000 | .05 | 10,000,000 |
| Electricity | 850,000,000 | .15* | 127,500,000 |
| Total | 15,788,000,000 | | $2,922,000,000 |

*Not given in Mr. Kinsman's report.

TABLE IV.

Cost of Power in Agriculture, 1923.

| | |
|---|---|
| Total cost | $2,922,000,000.00 |
| Cost per farm, (average) | 454.00 |
| Cost per improved acre, (average) | 5.81 |

In endeavoring to lower the cost of production of any commodity there are certain factors which cannot be controlled, while others are largely under the control of the operator. Let us examine the items entering into the cost of growing corn with a view of determining which items may or may not be within the control of the operator.

Land is the largest item, and at the same time, the one over which we have the least control. The cost of labor may be under control to the extent that by using modern equipment it may be reduced to a minimum, although the actual cost of labor per man hour cannot be controlled. Power is an item that the writer believes lends itself to the possibilities of lowering the costs of production.

3. Relative Cost of Power from Different Sources.

Plate III shows the relative cost of power from various sources as found by Kinsman in 1923. According to this data, animal power costs almost twice as much as mechanical power, for this year. It is well known that costs fluctuate from year to year. Rather than to be carried away by this striking comparison, the writer wishes to present a study of costs over a period of years, in an effort to arrive at some average that would furnish a satisfactory comparison.

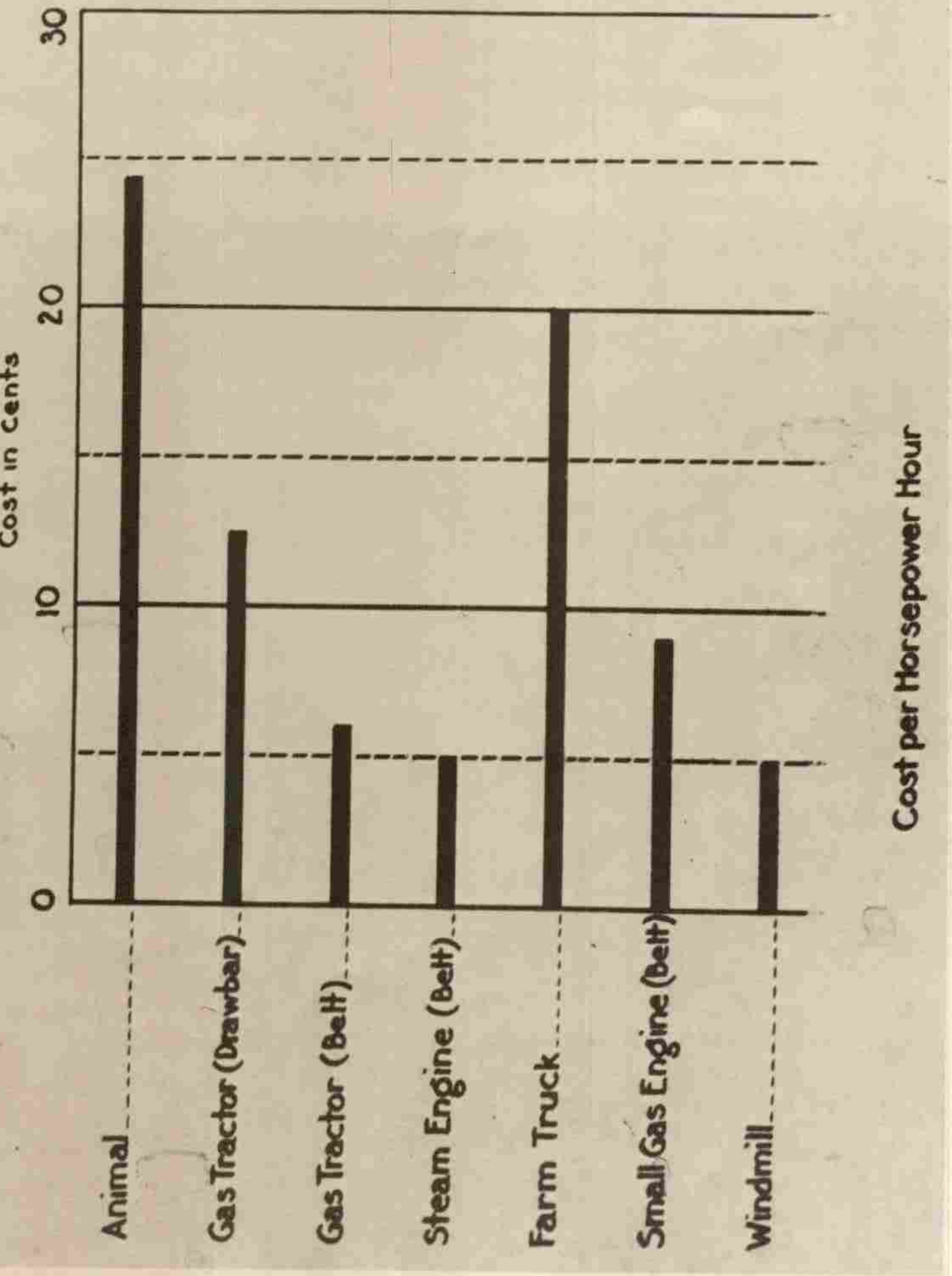



Plate III Average cost per horsepower hour of various kinds of power

Plate III

## VI. Cost of Horse Labor.

The data here presented on the cost of horse labor has been gathered from publications of various experiment stations and other reliable sources, and represents the results of investigations extending over a period of 16 years, from 1908 to 1923 inclusive.

### 1. Method of Obtaining Costs.

The different items entering into the cost of keeping a horse are given in Table V. Feed is by far the largest item of expense, varying anywhere from 60 to 70% of the total annual cost. The price of feed will therefore be the main cause of fluctuations in the cost of keeping a horse.

The cost per horse hour is determined by dividing the cost of keeping the horse per year by the number of hours worked per year. The latter is found to vary anywhere from 732 to 1152 hours, and is therefore one of the important factors in determining the cost of horse labor.

The two main factors in determining horse labor costs may therefore be stated as:

(a) Price of feed.

(b) Hours worked annually.

### 2. Cost Fluctuations.

Cost data is particularly difficult to deal with on account of fluctuations which occur from time to time and from place to place. In this study all available data has been made use of in an attempt to get averages that might be of greater value than the results of any individual investigations for the purposes here in involved.

Table VI is a tabulation of the available data giving the source and the year in which the results were obtained. The cost per horse hour is given in the body of the table. In the lowest line the cost is given per horse power hour.

(a) Place Fluctuations. The cost of horse labor varies considerably in different parts of the country. It may be noticed that the costs are higher for the eastern states for the same year. This may easily be accounted for by the higher prices of corn and oats in the east. For example, from 1909 to 1914 the cost per horse hour in Illinois and New York, (according to U. S. D. A. Bul. 560) was $0.0956 and $0.1422 respectively, a difference of $0.0466, or 49% higher in New York. At that time the price of corn in New York, as compared with Illinois, was 42% greater, and of oats 36% greater.

Where fluctuations occur between two farms in the same locality, the main reason is likely that of the number of hours worked per year. This is probably the cause of the difference in horse costs as given by Marshall County and Shelby County, Iowa, for the same years, 1922 and 1923.

TABLE V.

COST OF HORSE LABOR.

Data from U. S. Dept. of Agriculture Bul. 1298

Itemized summary of average annual costs and relative importance of various items of cost, 1921.

(279 farms, 1,975 horses.)

| Items | Cost per year | Per cent of total cost. |
|---|---|---|
| Feeding and bedding | $ 63.88 | 60.2 |
| Chores | 11,88 | 11.2 |
| Interest | 7.37 | 6.9 |
| Stabling | 7.28 | 6.9 |
| Depreciation | 6.70 | 6.3 |
| Harness costs | 4.78 | 4.5 |
| Shoeing | 1.90 | 1.8 |
| Miscellaneous | 2.29 | 2.2 |
| Total gross cost | $106.08 | 100.0 |
| Credit for manure | 6.87 | |
| Net cost | $ 99.21 | |

Actual average number of hours of horse labor on 279 farms, 723 hours.

Cost per horse hour $0.137

TABLE VI

HORSE LABOR COSTS PER HOUR

| Source | 1908 | 1909 | 1910 | 1911 | 1912 | 1913 | 1914 | 1915 | 1916 | 1917 | 1918 | 1919 | 1920 | 1921 | 1922 | 1923 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| University of Illinois Bul. 231 | | | | | | .0971 | .1254 | .1034 | .1027 | .1481 | .169 | | | | | |
| U. S. D. A. Bul. 1298 | | | | | | | | | | | | | | .137 | | |
| Cornell University Bul. 414 | | | | | | | .158 | .1548 | .1666 | .1970 | .2259 | .2434 | | | | |
| University of Minn. Bul. 179 | .09 | .09 | .09 | .09 | .09 | .0925 | .1141 | .1074 | .1198 | .1531 | | | | | | |
| Medina County, Ohio | | | | | | | | | | | | | .253 | | | |
| University of Missouri Bul. 152 | | | | | .079 | .079 | .079 | .079 | | .1415 | | | | | | |
| U. S. D. A. Bul. 997 | | | | | | | | | | | | | .245 | | | |
| U. S. D. A. Bul. 560 : Illinois | | .0956 | .0956 | .0956 | .0956 | .0956 | .0956 | | | | | | | | | |
| U. S. D. A. Bul. 560 : Ohio | | .1309 | .1309 | .1309 | .1309 | .1309 | .1309 | | | | | | | | | |
| U. S. D. A. Bul. 560 : New York | | .1422 | .1422 | .1422 | .1422 | .1422 | .1422 | | | | | | | | | |
| Marshall County, Iowa | | | | | | | | | | | | | | | .192 | .169 |
| Shelby County, Iowa | | | | | | | | x | | | | | | | .1278 | .198 |
| Average cost per horse hour | .09 | .1147 | .1147 | .1147 | .1075 | .1062 | .1209 | .1111 | .1296 | .1579 | .1974 | .2434 | .249 | .137 | .1599 | .183 |
| Average cost per H. P. hour | .12 | .153 | .153 | .153 | .143 | .142 | .161 | .148 | .173 | .21 | .263 | .324 | .332 | .183 | .213 | .244 |

TABLE VII

FEED PRICES 1908 - 1923 (inclusive)

| Year | Corn, per Bu. | Oats, per Bu. | Hay, per Ton. |
|---|---|---|---|
| 1908 | 60¢ | 47.3¢ | $ 9.14 |
| 1909 | 58.6 | 40.6 | 10.58 |
| 1910 | 48.0 | 34.4 | 12.14 |
| 1911 | 61.8 | 45.0 | 14.29 |
| 1912 | 48.7 | 31.9 | 11.79 |
| 1913 | 69.1 | 39.2 | 12.43 |
| 1914 | 64.4 | 43.8 | 11.12 |
| 1915 | 57.5 | 36.1 | 10.63 |
| 1916 | 88.9 | 52.4 | 11.22 |
| 1917 | 127.9 | 66.6 | 17.09 |
| 1918 | 136.5 | 70.9 | 20.13 |
| 1919 | 134.5 | 71.5 | 20.08 |
| 1920 | 67 | 46 | 17.76 |
| 1921 | 42.3 | 30.2 | 12.11 |
| 1922 | 65.8 | 39.4 | 12.56 |
| 1923 | 72.7 | 41.5 | 14.07 |

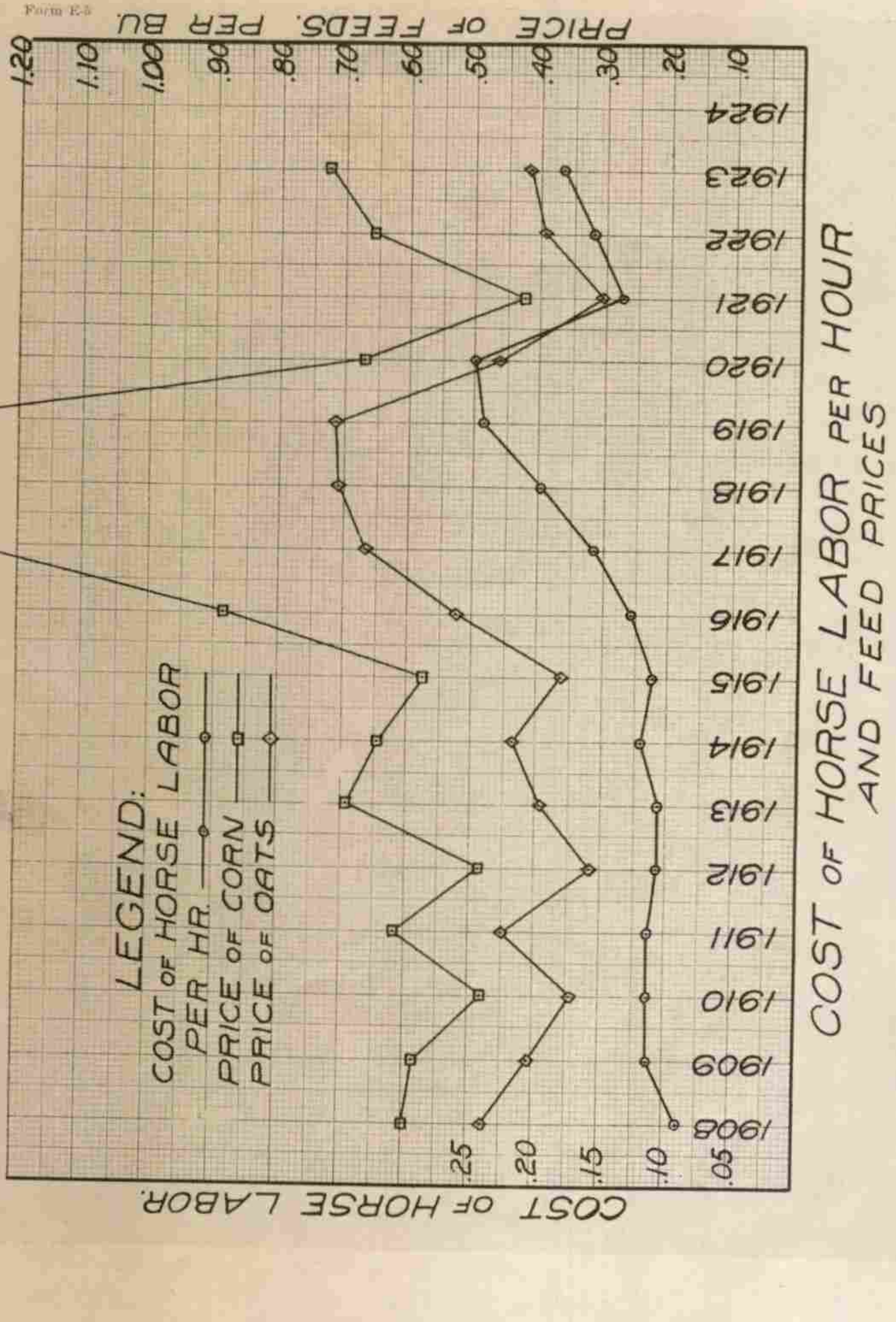

Form E-5
PRICE OF FEEDS. PER BU.
1.20
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
LEGEND:
COST OF HORSE LABOR
PER HR.
PRICE OF CORN
PRICE OF OATS
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
.25
.20
.15
.10
.05
COST OF HORSE LABOR.
COST OF HORSE LABOR PER HOUR
AND FEED PRICES

Plate IV

(b) Time fluctuations. Plate IV shows the cost per horse hour from 1908 to 1923 according to averages obtained from the data in Table VI. It will be seen that there is a large variation in costs during that time. Table VII gives the price of corn, oats and hay over the same period. The price of corn and oats has been plotted on the same plate. A glance at the plate will show that the horse labor costs follow very closely the feed prices over that period.

3. Power Developed per Horse.

One weakness of all data available on this subject is that no record of the amount of work done per horse is available. The amount of power that a horse develops depends upon the load he pulls and the rate at which he travels. To develop one horse-power, if he pulls a load of 150 lbs, he must travel at 2½ miles per hour. This is more than the average horse pulls, and besides, rest periods are required, so that the average speed would be reduced to about 2 miles per hour.

A horse hour is not equivalent to a horse-power hour, though this is a mistaken assumption often made even by engineers.

Thurston, in "The Animal as a Machine and a Prime Mover", states: "The horse, if of average weight and condition, should do a day's work at the rate of about two-thirds of a horse-power." Rennie rated the average draft horse at two-thirds of a "Watt" horse-power. Watt's experiments showed that the average horse, walking at the rate of 2½ miles per hour, pulled 100 lbs., which is equivalent to 22,000 foot-pounds per minute, after which he decided to add 50% for good measure and call 33,000 foot-pounds per minute one horse-power. Watt's unit of "horse power" is universally used to-day.

It is probably true that bigger horses are used at present than were used when these early experiments were made. It is generally accepted that a horse should pull one-tenth of his weight. Taking the average farm horse at 1,400 lbs., which is liberal, and assuming an average rate of 2 miles per hour, the power developed is $\frac{1400 \times 2 \times 88}{10 \times 33{,}000} = .744$ or approximately 3/4 H. P. This figure will be used in comparing horse and tractor costs.

## VII. Tractor Costs.

The material available on tractor costs is more limited than that on horse costs, and naturally not available over as long a period of time. Tractors were not used extensively for field work until about 1912. Records of costs that can be given much credit are available only for recent years.

### 1. Method of Obtaining Costs.

The items entering into the cost of tractor power in order of importance are: depreciation, fuel, repairs and upkeep, interest, oil and housing.

U. S. D. A. Bulletin No. 1297 gives the following table for 1922, bearing on the costs of these items.

TABLE VIII

Average Cost per Year and per Day, 1922

Two-Plow and Three-Plow Tractors

| Item | Cost per year | | Cost per day | |
|---|---|---|---|---|
| | 2-plow | 3-plow | 2-plow | 3-plow |
| Depreciation | $78.00 | $129.00 | $2.41 | $4.53 |
| Fuel | 81.00 | 89.00 | $2.51 | $3.12 |
| Repair and upkeep | 35.00 | 33.00 | 1.08 | 1.16 |
| Interest | 17.00 | 31.00 | .53 | 1.09 |
| Oil | 18.00 | 19.00 | .55 | .67 |
| Other costs | 11.00 | 15.00 | .34 | .53 |
| Total | 240.00 | 316.00 | 7.42 | 11.10 |

Depreciation is the largest item entering into the cost of operating a tractor. According to U. S. D. A. Bul. 997, the average life of tractors was found to be 6.7 years. This is based on a 1920 survey. According to the same source the average price of a 2-plow and 3-plow Tractors in 1920 was $972.00 and $1,354.00 respectively. This divided by the average life gives the annual depreciation, which would be $145.00 for the 2-plow and $202.00 for the 3-plow tractor.

The annual depreciation given in Table VIII for 1922 is considerably lower than this, which may be accounted for by the lower first cost in 1922. The average cost of 2-plow tractors in 1922 was about $730.00, from figures given in U. S. D. A. Statistical Bulletin No. 5.

The only data available on tractor costs that might be used for purposes of comparison with horse labor costs is given in cost per day or per hour for 2-plow and 3-plow tractors. Here again certain assumptions must be made in order to have the figures in the form of cost per horse-power hour.

Table IX gives cost data for three years, 1918, 1920 and 1922, from three different sources.

TABLE IX.

Cost of Tractor Power for Field Work.

| Source. | Year | Cost per day: 2-plow | Cost per day: 3-plow | Cost per hr: 2-plow | Cost per hr: 3-plow | Cost her H.P. hr.: 2-pl | Cost her H.P. hr.: 3-pl | Cost her H.P. hr.: Av. |
|---|---|---|---|---|---|---|---|---|
| Iowa Circular 63 | 1918 | | | .786 | 1.015 | .119 | 1025 | .111 |
| U. S. D. A. Bul.997 | 1920 | 12.67 | 17.73 | 1.267 | 1.773 | .192 | .179 | .185 |
| U. S. D. A. Bul.1297 | 1922 | 7.42 | 11.10 | .742 | 1.110 | .112 | .112 | .112 |

2. Power developed by Tractors.

The question arises, how much power is required to pull a two furrow plow at average tractor speed? The draft per bottom in clay loam, plowing six inches deep is about 500 lbs. Assuming that the tractor travels at 2½ miles per hour, the power required per bottom would be:

$$\frac{2.5 \times 88 \times 500}{33,000} = 3.3 \text{ H.P.}$$

The 2-plow tractor would then develop 6.6 H. P. and the 3-plow tractor 9.9 H. P. The last column in Table IX is computed on that basis.

## VIII. Animal and Tractor Power Compared.

As the purpose of this study is chiefly to obtain a comparison between the use of animal power and mechanical power for field work, it will be well to summarize here on that phase of the problem.

### 1. Sources of Power for Field Work.

TABLE X.

Comparison of Mechanical and Animal Power used on United States Farms for Field Work, 1923

(From National Farm Power Survey.)

| Source | Primary H. P. | % | H. P. Hrs.Dev'pd: annually | % |
|---|---|---|---|---|
| Animal | 21,660,000 | 84.5 | 6,710,000,000 | 88.2 |
| Gas Tractors | 4,000,000 | 15.5 | 900,000,000 | 11.8 |
| Total | 25,660,000 | 100.0 | 7,610,000,000 | 100.0 |

This table shows clearly to what a large extent animal power is used for field work. Of the total available power for field work, 84.5% is animal power. If we examine the horse-power hours developed annually by the two sources, the comparison is still more striking; 88.2% of all field work in the United States is at present done by work animals.

It will be noticed that no figures for steam engines appear in this table. The amount of field work done with steam engines at the present time is so small that its omission from this table will cause no appreciable error. Mr. Kinsman does not give figures for the steam engine as used for field work.

2. Comparative Costs of Power From the Two Sources.

Since the tractor costs data is only given for three different years, for purposes of comparison the horse labor costs will be taken for the same years. Table XI gives the cost of power from the two sources per horse-power hour for 1918, 1920 and 1922.

TABLE XI.

Cost of Power for Field Work.

| Source | 1918 | 1920 | 1922 | Average |
|---|---|---|---|---|
| Horse | .263 | .332 | .213 | .269 |
| Tractor | .111 | .185 | .112 | .136 |

Plate V shows graphically the horse and tractor costs over the period for which the data was obtained. It will be

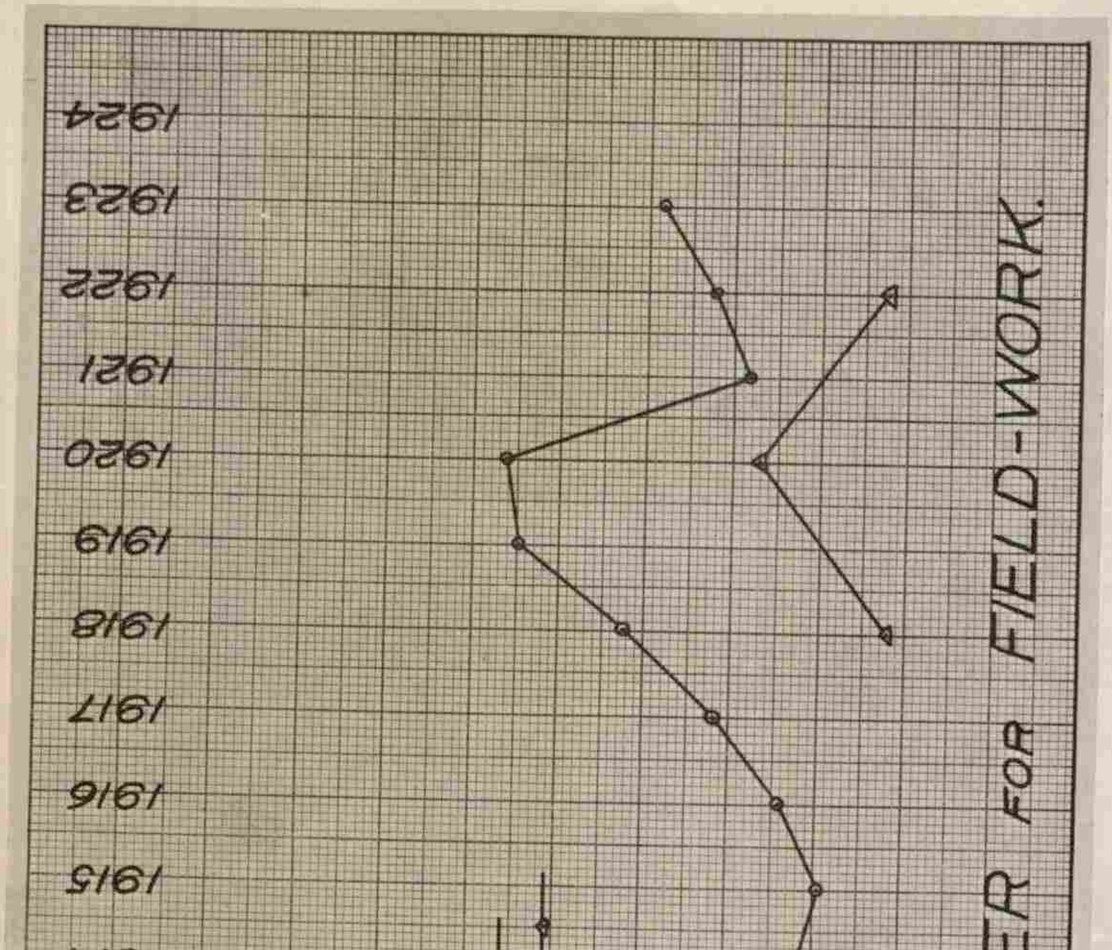

COST OF POWER FOR FIELD-WORK.
LEGEND:
HORSE
TRACTOR
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
.30
.25
.20
.15
.10
.05

Plate V

noticed that for the years where figures are given for both sources the relation is practically the same. The fluctuations in either case would be affected by much the same economic conditions from time to time. According to these records, horse labor costs almost twice as much as mechanical power where the latter is used.

3. Summary of Comparisons.

Plate VI gives a graphical summary of the field power situation in the United States at the present time. It must be inferred from this comparison that an increased use of mechanical power would result in lowering the cost of production. To what extent this might be carried is not easily determined. It would be interesting to figure what saving might be made by an entire displacement of animal power.

Cost per 100 H. P. Hours;

| | | |
|---|---|---|
| With present distribution, | 88.2 x .269 + 11.8 x .136 = | \$25.30 |
| All mechanical power, | 100 x .136 = | \$13.60 |
| Difference | | \$11.70 |

$$\text{Saving: } \frac{11.70 \times 100}{25.30} = 46\%$$

It is not predicted that mechanical power will entirely replace animal power. It seems reasonable to suppose that some point of balance may be reached where a further increase of the use of mechanical power would not be economical. It seems

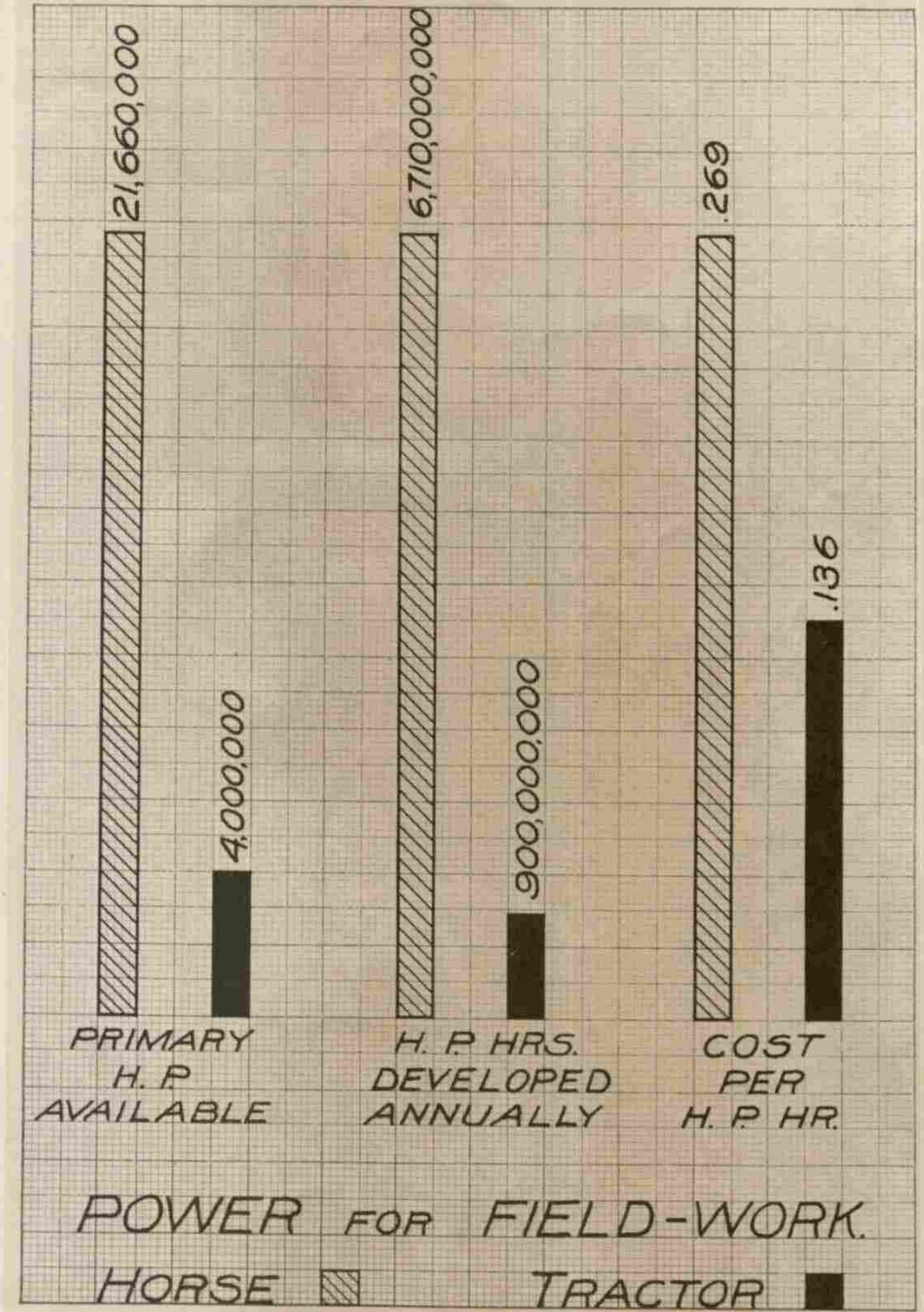

21,660,000
4,000,000
6,710,000,000
900,000,000
.269
.136
PRIMARY
H. P.
AVAILABLE
H. P. HRS.
DEVELOPED
ANNUALLY
COST
PER
H. P. HR.
POWER FOR FIELD-WORK.
HORSE
TRACTOR

Plate VI

obvious, however, that that point is far off, and that a very great reduction in the cost of production of agricultural products may be effected by working towards an increased use of mechanical power for field work.

IX. Power Requirements of Farm Crops.

The amount of power used for different farm operations in the United States hasaalready been given. Table II shows the relation between the power required for the major operations. Plowing consumes almost one-third of all power used for field work. It is likely that plowing will always be the most important field operation and the one which takes the most power, although it is an operation performed only once each year upon the same piece of land.

Cultivating inter-tilled crops is an operation which consumes a great deal of power, especially in the corn-belt and the cotton growing regions of the south. Although cultivating is comparatively light work as compared with plowing, it may take almost as much power on some farms, as the same land is cultivated three or four times in a season. In 1923, according to Table II, cultivating took 13.2% of all power used for field work in the United States. This is not a large percentage, but the growing of inter-tilled crops is on the increase. With the introduction of earlier varieties the corn-belt has been gradually moving northward; the practice of growing small grains in rows is coming into use in some sections, and with more diversified farming many fodder and root crops requiring inter-tillage have been included in the rotation. Cultivating growing crops is one farm operation which, as yet, is not done successfully with mechanical power. Horses are used exclusively for this operation.

In order to get a better understanding of the power requirements offfarm crops at the present time, a classification of crops is here presented, classifying all major crops as cultivated or non-cultivated crops.

1. Cultivated Crops.

Crops requiring cultivation during the growing season include corn, cotton, grain sorghums, tobacco, potatoes, sweet potatoes, sugar cane and sugar beets. Some of the small grains should be included in this class as well. Table XII gives the acreage of these crops and their distribution by states in 1923. No data was available on the acreage of small grains grown in rows, so this item was omitted. According to this data, the acreage of cultivated crops in the United States in 1923 was 155 million acres, or approximately 47% of all field crops.

2. Non-cultivated Crops.

In Table XIII is given the acreage and distribution of crops which are not cultivated during the growing season.

## TABLE XII

## CULTIVATED CROPS

## DISTRIBUTIONS BY STATES 1923.

(Acres in Thousands)

| State | Corn | Cotton | Tobacco | Grain Sorghums | Potatoes | Sweet Potatoes | Sugar Cane | Sugar Beets | Total Culti-vated Crops. |
|---|---|---|---|---|---|---|---|---|---|
| Maine | 18 | | | | 124 | | | | 142 |
| N.H. | 26 | | | | 13 | | | | 39 |
| Ver. | 84 | | | | 24 | | | | 108 |
| Mass. | 59 | | 10 | | 26 | | | | 95 |
| R.I. | 12 | | | | 2 | | | | 14 |
| Conn. | 76 | | 29 | | 23 | | | | 128 |
| N.Y. | 758 | | 2 | | 323 | | | | 1,083 |
| N.J. | 236 | | | | 80 | 18 | | | 334 |
| Pa. | 1,541 | | 45 | | 249 | 2 | | | 1,837 |
| Del. | 183 | | | | 10 | 9 | | | 202 |
| Md. | 642 | | 24 | | 49 | 9 | | | 2,724 |
| Va. | 1,847 | 73 | 182 | | 152 | 44 | | | 2,298 |
| W.Va. | 592 | | 9 | | 49 | 3 | | | 653 |
| N.C. | 2,603 | 1,678 | 552 | | 46 | 100 | | | 4,979 |
| S.C. | 1,980 | 2,030 | 102 | | 32 | 94 | 10 | | 4,248 |
| Ga. | 4,034 | 3,433 | 17 | | 22 | 137 | 45 | | 7,688 |
| Fla. | 820 | 143 | 4 | | 19 | 30 | 28 | | 1,044 |
| Ohio | 3,899 | | 47 | | 126 | 3 | | 46 | 4,121 |
| Ind. | 5,003 | | 22 | | 75 | 3 | | | 5,103 |
| Ill. | 8,995 | | | | 104 | 8 | | | 9,107 |
| Mich. | 1,686 | | | | 314 | | | 131 | 2,131 |
| Wisc. | 2,253 | | 44 | | 272 | | | 20 | 2,589 |
| Minn. | 4,297 | | | | 399 | | | | 4,696 |
| Ia. | 10,571 | | | 6 | 81 | 4 | | | 10,662 |
| Mo. | 6,562 | 339 | 6 | 13 | 93 | 14 | | | 7,027 |
| N.D. | 842 | | | | 158 | | | | 1,000 |
| S.D. | 4,208 | | | | 88 | | | | 4,296 |
| Nebr. | 8,244 | | | 26 | 111 | | | 60 | 8,441 |
| Kans. | 5,629 | | | 1,598 | 60 | 3 | | | 7,290 |
| Ky. | 3,083 | [illegible] | 578 | | 58 | 20 | | | 3,739 |

CULTIVATED CROPS (Cont'd).

DISTRIBUTION BY STATES 1923.

(Acres in Thousands)

| State | Corn | Cotton | Tobacco | Grain Sorghums | Potatoes | Sweet Potatoes | Sugar Beets | Sugar Cane | Turnips and Mangolds | Total Cultivated Crops. |
|---|---|---|---|---|---|---|---|---|---|---|
| Tenn. | 3,018 | 1,167 | 146 | | 32 | 35 | | | | 4,398 |
| Ala. | 3,310 | 3,149 | | | 44 | 113 | | 70 | | 6,686 |
| Miss. | 2,327 | 3,298 | | | 15 | 101 | | 33 | | 5,770 |
| La. | 1,604 | 1,395 | 1 | | 26 | 78 | | 332 | | 3,436 |
| Tex. | 5,213 | 14,081 | | 1,891 | 35 | 86 | | 17 | | 21,323 |
| Okla. | 3,264 | 3,295 | | 1,523 | 42 | 30 | | | | 8,154 |
| Ark. | 2,002 | 3,054 | | | 33 | 40 | | 4 | | 5,133 |
| Mont. | 365 | | | | 36 | | | | | 401 |
| Wyo. | 150 | | | | 18 | | | | | 168 |
| Col. | 1,490 | | | 336 | 110 | | 182 | | | 2,118 |
| N.Mex. | 221 | | | 205 | 3 | 1 | | | | 430 |
| Ariz. | 33 | 128 | | 35 | 4 | 2 | | | | 202 |
| Utah | 31 | | | | 16 | | 84 | | | 131 |
| Nev. | 1 | | | | 5 | | | | | 6 |
| Idaho | 73 | | | | 67 | | 47 | | | 187 |
| Wash. | 74 | | | | 52 | | | | | 126 |
| Ore. | 71 | | | | 44 | | | | | 115 |
| Cal. | 128 | 233 | | 143 | 52 | 6 | 70 | | | 632 |
| U.S. | 104,158 | 37,348 | 1,820 | 5,776 | 3816 | [illegible],993 | 640 | 539 | | 155,090 |
| P.E.I. | 7 | | | | 35 | | | | 8 | 50 |
| N.S. | 1 | | | | 38 | | | | 16 | 55 |
| N.B. | 5 | | | | 75 | | | | 16 | 96 |
| Que. | 173 | | | | 206 | | | | 49 | 428 |
| Ont. | 704 | | | | 172 | | 21 | | 105 | 1,002 |
| Man. | 29 | | | | 39 | | | | 5 | 73 |
| Sask. | 38 | | | | 56 | | | | 9 | 103 |
| Alta. | 15 | | | | 42 | | | | 9 | 66 |
| B.C. | 5 | | | | 19 | | | | | 24 |
| Can. | 977 | | | | 682 | | 21 | | 217 | 1,897 |
| U.S. & Can. | 105,135 | 37,348 | 1,820 | 5,776 | 4498 | | 661 | | 217 | 156,987 |

TABLE XIII

NON-CULTIVATED CROPS
(Crops not Sown in Rows)

DISTRIBUTION BY STATES 1923

(Acres in Thousands)

| State | Wheat | Oats | Barley | Rye | Flax | Buckwheat | Rice | | Hay (tame) | Total Non Cultivated Crops. |
|---|---|---|---|---|---|---|---|---|---|---|
| Maine | 6 | 125 | 3 | | | 9 | | | 1,245 | 1,388 |
| N.H. | | 18 | 1 | | | 1 | | | 441 | 461 |
| Ver. | 4 | 88 | 9 | | | 4 | | | 918 | 1,023 |
| Mass. | | 9 | | 3 | | 1 | | | 434 | 447 |
| R. I. | | 1 | | | | | | | 45 | 46 |
| Conn. | | 10 | | 5 | | 2 | | | 320 | 337 |
| N.Y. | 403 | 1,017 | 190 | 58 | | 214 | | | 4,919 | 6,801 |
| N.J. | 74 | 68 | | 65 | | 10 | | | 312 | 529 |
| Pa. | 1,283 | 1,170 | 12 | 215 | | 227 | | | 2,920 | 5,827 |
| Del. | 106 | 7 | | 6 | | 8 | | | 81 | 208 |
| Md. | 543 | 59 | 4 | 17 | | 9 | | | 400 | 1,032 |
| Va. | 838 | 163 | 10 | 42 | | 18 | | | 1,010 | 2,081 |
| .Va. | 228 | 196 | | 10 | | 33 | | | 753 | 1,220 |
| .C. | 544 | 231 | | 58 | | 8 | | | 784 | 1,625 |
| .C. | 175 | 447 | | 7 | | | 8 | | 480 | 1,117 |
| a. | 189 | 521 | | 20 | | | 3 | | 772 | 1,505 |
| la. | | 33 | | | | | 2 | | 132 | 167 |
| hio | 2,350 | 1,516 | 74 | 84 | | 23 | | | 3,070 | 7,117 |
| nd. | 2,076 | 1,739 | 30 | 299 | | 6 | | | 2,210 | 6,360 |
| ll. | 3,479 | 3,860 | 288 | 230 | | 6 | | | 3,280 | 11,083 |
| ich. | 976 | 1,528 | 150 | 467 | | 53 | | | 3,105 | 6,279 |
| isc. | 119 | 2,539 | 465 | 342 | 8 | 28 | | | 3,187 | 6,688 |
| inn. | 1,728 | 4,142 | 962 | 912 | 527 | 49 | | | 2,016 | 10,336 |
| a. | 787 | 5,639 | 161 | 54 | 9 | 5 | | | 3,351 | 10,006 |
| o. | 2,919 | 1,380 | 6 | 26 | | 1 | | | 3,310 | 7,642 |
| .D. | 8,262 | 2,388 | 1,361 | 1,288 | 1094 | | | | 1,079 | 15,472 |
| .D. | 2,812 | 2,304 | 890 | 304 | 284 | 9 | | | 1,050 | 7,653 |
| ebr. | 3,174 | 2,456 | 339 | 132 | 4 | 1 | | | 1,584 | 7,690 |
| ans. | 8,299 | 1,338 | 967 | 41 | 24 | | | | 1,630 | 12,299 |
| y. | 620 | 225 | 7 | 20 | | 9 | | | 1,130 | 2,011 |

NON-CULTIVATED CROPS (Cont'd)

(Crops not Sown in Rows.)

DISTRIBUTION BY STATES 1923.

(Acres in Thousands)

| State | Wheat | Oats | Barley | Rye | Flax | Buckwheat | Rice | Mixed Grains | Hay (tame) | Total Non-Cultivated Crops. |
|---|---|---|---|---|---|---|---|---|---|---|
| Tenn. | 442 | 205 | 17 | 20 | | 3 | | | 1,354 | 2,041 |
| Ala. | 20 | 277 | | 1 | | | | | 761 | 1,059 |
| Miss. | 4 | 120 | | | | | 1 | | 471 | 596 |
| La. | | 56 | | | | | 480 | | 214 | 750 |
| Texas | 1,559 | 1,470 | 108 | 17 | | | 159 | | 711 | 4,024 |
| Okla. | 3,300 | 1,200 | 129 | 37 | | | | | 936 | 5,602 |
| Ark. | 70 | 269 | | 1 | | | 133 | | 556 | 1,029 |
| Mont. | 3,531 | 673 | 97 | 192 | 110 | | | | 1,087 | 5,690 |
| Wyo. | 175 | 175 | 28 | 24 | 1 | | | | 750 | 1,153 |
| Col. | 1,390 | 188 | 221 | 73 | | | | | 1,203 | 3,085 |
| N.Mex. | 108 | 58 | 11 | 2 | | | | | 158 | 337 |
| Ariz | 42 | 19 | 36 | | | | | | 175 | 272 |
| Utah | 272 | 81 | 22 | 11 | | | | | 523 | 909 |
| Nev. | 20 | 3 | 6 | | | | | | 180 | 209 |
| Idaho | 1,052 | 170 | 93 | 14 | | | | | 1,060 | 2,389 |
| Wash. | 2,470 | 210 | 85 | 23 | | | | | 1,005 | 3,793 |
| Ore. | 1,111 | 270 | 88 | 37 | | | | | 984 | 2,490 |
| Cal. | 748 | 162 | 1,095 | | | | 106 | | 2,066 | 4,177 |
| U.S. | 58,308 | 40,833 | 7,905 | 5,157 | 2,061 | 737 | 892 | | 60,162 | 176,055 |
| P.E.I. | | | 8 | | | 3 | | 17 | 258 | 286 |
| N.S. | 14 | 136 | 7 | | | 8 | | 4 | 558 | 727 |
| N.B. | 23 | 314 | 7 | 6 | | 54 | | 4 | 700 | 1,108 |
| Que. | 145 | 2,252 | 155 | 19 | 6 | 167 | | 140 | 4,028 | 6,912 |
| Ont. | 938 | 3,034 | 434 | 153 | 4 | 198 | | 552 | 3,796 | 9,109 |
| Man. | 3,125 | 1,851 | 968 | 422 | 67 | | | 13 | 230 | 6,676 |
| Sask. | 12,332 | 5,098 | 636 | 901 | 466 | | | 29 | 262 | 14,724 |
| Alta. | 5,765 | 1,614 | 378 | 603 | 22 | | | 14 | 1,537 | 9,933 |
| B.C. | 46 | 57 | 7 | 7 | | | | 5 | 214 | 336 |
| Can. | 22,388 | 14,356 | 2,600 | 2,111 | 565 | 430 | | 778 | 11,583 | 54,811 |
| U.S. & Can. | 80,696 | 55,189 | 10,505 | 7,268 | 2,626 | 1,167 | 892 | 778 | 17,745 | 230,866 |

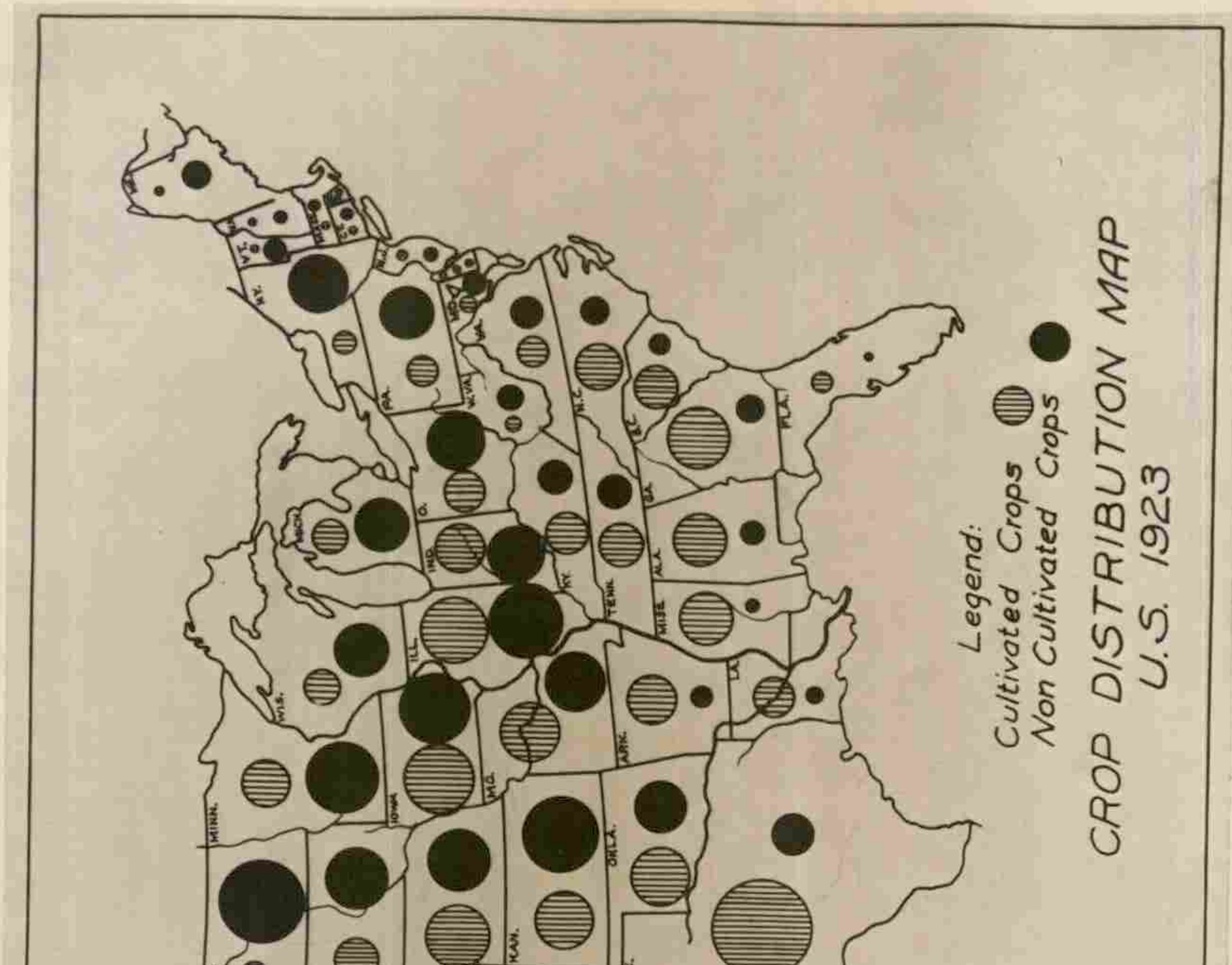

CROP DISTRIBUTION MAP
U.S. 1923
Legend:
Cultivated Crops
Non Cultivated Crops
Total U.S.

Plate VII

This includes wheat, oats, barley, rye, flax, buckwheat, rice and hay crops. A small percentage of the small grains and hay crops should properly be classified as rowed crops, so it may be estimated fairly that one-half of the crops in the United States, by acreage, are grown in rows and cultivated during the growing season. The data contained in these tables is presented graphically in Plate VII.

## X. Limitations of the Tractor in Field Operations.

The tractor, where used, has been shown to be a much cheaper source of power than horses. Why then is the tractor not used to a greater extent? The answer is that the utility of the tractor is too limited. The tractor is used chiefly for plowing and fitting the ground, so far as field operations are concerned. Cultivating rowed crops is not a tractor operation, and as this is such an important operation in modern agriculture, and likely to become more so, the tractor does not fit well into the cycle of farm operations.

Illinois Bulletin No. 231 classifies farm operations into three classes: first, horse or non-tractor work; second, doubtful tractor work; and third, tractor work. According to this classificatiom the major field operation range as follows:

1. Non-tractor operations.
   - (a) Cultivating rowed crops
   - (b) Planting corn
   - (c) Husking Corn

(d) Mowing, raking and tedding hay.

(e) Sowing grass seed.

(f) Hauling bundles to thresher or ensilage cutter.

2. Doubtful tractor operations.

(a) Drilling small grains.

(b) Cutting small grains or corn with binder.

(c) Pulling hay-loader.

(d) Hauling feed and fertilizer. (more than one wagon.)

3. Tractor operations.

(a) Plowing.

(b) Disking.

(c) Harrowing.

(d) Cutting stalks. (with disk)

(e) Dragging.

(f) Cultivating bare fallow.

## XI. Displacement of Horses by Use of Tractor.

On account of the limited application of the tractor it does not replace many horses, especially on corn-belt farms. The peak load on the corn-belt farm occurs in May during the operations of plowing and preparing the land. The use of a tractor will relieve the situation at that time, but is unable to take care of subsequent inter-tillage work. On non-tractor farms the number of horses is determined by the amount of work which must be done in May while on tractor farms it is determined by the work of cultivating which occurs in June and July.

The difference in the load at those two periods is not great enough to have much effect upon the number of horses kept.

A very bad feature of not being able to use the tractor for cultivating corn is that this work comes during the hottest days of summer when animals are least efficient. The tractor, on the contrary, works at its maximum efficiency during hot weather. It is not uncommon to pass a field of corn in June or July when the thermometer registers 100 degrees in the shade, and see horses, foaming with sweat and fighting with the flies, pulling a cultivator, while the tractor, which plowed and prepared the land, stands idle in the shed, or perhaps in the fence corner where depreciation goes on even more rapidly.

According to U. S. D. A. Farmer's Bulletin 719, the average tractor on corn-belt farms replaces only about four horses; some investigations have given a figure as low as three.

The place of the tractor on corn-belt farms may be appreciated from the following rule laid down by the author of U. S. D. A. Farmer's Bulletin 1093, Mr. L. A. Reynoldson, who says: "Keep enough horses to cultivate corn and do other necessary work which must be done at the same time but which the tractor cannot do." This rule, it must be admitted, is perfectly sound when applied to the modern tractor. But, while such a rule must be followed, there is little to be gained by using more mechanical power.

## XII. Proposed Solution for the Farm Power Problem.

The farm power situation has been presented rather fully. To sum up, it may be stated briefly as follows:

The United States farmer has two sources of power for field work, animal and mechanical; the former supplies 88% of the power but is found to cost twice as much per horse-power hour as mechanical power, where the latter is used.

Greater use of mechanical power therefore presenta a means of lowering the cost of production of farm crops. The modern tractor can do little to solve this problem, as its range of application is too limited. Tractors designed for special purposes, as for example the motor-cultivator, which has been used to some extent, will do little to lower the cost of production, as additional power units mean too great an overhead expense. Mechanical power must be made more versatile before it can economically be brought into more extensive use.

The writer believes that the solution of this problem lies with the tractor designer and manufacturer. The problem, it is believed, would be solved to a large degree by the design of a well built, light weight, general-purpose tractor, suitable for cultivating corn and other rowed crops, and yet equally adaptable to plowing and belt work as the conventional machine.

# SECTION II

## THE DEVELOPMENT OF THE TRACTOR

The progress in the use of mechanical power in industry has been stupendous. Perhaps the most amazing development ever viewed by civilization has been that of the automotive industry, which in little more than two decades has sprung up from its infancy to one of the greatest industries of the country. It takes no prophet to see that we are only just entering the "motor age." It would be contrary to all natural evolution in the affairs of mankind if this rapid development were to cease all of a sudden and not be carried further. That development in the motor world will progress as rapidly, if not more so, in the next twenty years as it has in the last corresponding period seems inevitable to those who have read and noted the progress of humanity.

The gas tractor and the automobile had their beginning almost simultaneously. There are now over 15 million automobiles and trucks in the United States, and almost half a million tractors.

### I. The Early Tractor.

It was the success of the stationary and portable engine used for belt work to replace the sweep-power and the treadmill that first gave rise to the use of mechanical power for field work. The portable steam engine was provided with drive wheels, gear transmission and steering wheels and the steam tractor was ready for use. The early gas tractor was a similar development of the stationary gas engine mounted on a frame and geared to a pair of drive wheels.

The tractor was at first a crude, heavy machine with all working parts exposed. How the cost of operating the early tractors compared with the cost of animal power we do not know. It is more than likely that the comparison was not in favor of the tractor. The tractor came in first as an auxiliary, rather than as a substitute for the horse. It was desired to break up large tracts of land and to do it quickly. To do this with animal power would have been impossible, as the supply of that source was limited and could not be immediately increased. The big steam and gas tractors, pulling eight to twelve plows, found favor for reasons of expediency.

## II. Tendency in Modern Tractor Design

The time came when this first function of the tractor had been fulfilled. The land was broken up and it required less power to perform subsequent operations. During this period the tractor underwent some improvements, but certain defects, not so apparent when working on sod, became more serious when working on plowed ground. Excessive weight was one of those drawbacks. The rolling resistance on plowed ground is much greater than on the firm sod, and therefore the efficiency of the tractor was cut down with increased tillage of the soil. No special attempt was made to enclose the working parts of the early tractor. When plowing sod this was not a serious objection, but with increased tillage came the dust menace, which makes it essential to have all working parts enclosed.

In spite of its drawbacks, it must be said that steady progress has been made in improving the tractor from its first appearance, particularly in the strictly mechanical engineering field. Comparing the tractor of to-day with that of ten years ago, we have a machine which is lighter in weight, more economical; in fuel consumption, suited for lower grade fuels; practically all working parts are enclosed; air cleaners protect the cylinders from excessive wear; the mechanical efficiency has been improved by the use of roller and ball bearings in the transmission and the replacement of wearing parts has been made easier and more general.

It is the application of the tractor to agriculture that has been neglected by the designer, so that the range of usefulness of the tractor is not much wider than it was ten years ago. Tractors are still being built chiefly for plowing and belt work, although a number of attempts have been made, and are being made, to extend their usefulness to other channels.

## III. Precedent in General-Purpose Tractor Design

The general-purpose tractor is not a new idea; several companies have built general-purpose tractors, but so far none of them have made much progress and some have gone out of business.

One thing that has gone against the general-purpose tractor is that it has been felt to be a compromise between a plowing engine and a motor cultivator without much success at either. In some cases the arrangement for belt work has been far from satisfactory, --another case where an unsatisfactory compromise has been made. For this reason, the general-purpose tractor has often been thought of in the same way as a general-purpose horse, which is supposed to be adaptable to heavy farm work, yet light enough to be hitched to a buggy and driven to town; or the dual-purpose cow, which is expected to produce a fairly large amount of milk and yet raise good beef calves. A compromise of that kind is extremely difficult, if at all possible to make satisfactorily on account of biological difficulties which arise. It should be much simpler, however, to make such a compromise when mechanical principles only are involved.

It is the belief of the writer that the reason the general-purpose tractor has failed in a number of forms in which it has appeared is due to the fact that these compromises have not been properly made, and further, that with careful planning and designing, it is possible to combine these various functions in one machine without impairing any of the major functions while trying to develop others.

## SECTION III.

## THE REQUIREMENTS OF A GENERAL-PURPOSE TRACTOR.

The purpose of this section is to present a study of the desirable features in tractor design with special application to the general-purpose tractor. These requirements may be grouped as follows:

I. Long recognized requirements for which all designers are striving:

1. Efficiency. (a) Fuel economy.
2. Durability. (b) Mechanical efficiency.
3. Low cost.
4. Simplicity.
5. Accessibility.
6. Protection of working parts from dust.
7. Good lubrication of all working parts, without constant care.
8. Renewal of working parts.
9. Care and safety of operation.

II. Special requirements to meet the demands of modern agriculture.

10. Cultivating attachment.
11. Width of track to fit rows, but not too wide for plowing.
12. Clearance to work in fields of growing corn.

13. Size, such as to be applicable to practical unite of tillage, seeding, harvesting, and belt machines.
14. Unit assembly of such parts as engine and transmission.
15. Speeds of tractor suitable for all farm machines.
16. Light weight, with provision for additional weight when required.
17. Control easy and quick for cultivating.
18. Differential brakes for quick turning when cultivating.
19. Power take-off by tumbling shaft.
20. Belt pulley in good position to receive belt.
21. Compact arrangement, consistent with accessibility.
22. Neat appearance.

Each of these points will now be discussed more in detail.

1. Efficiency.

Efficiency has long been held as one of the most important points in tractor design. This field has consequently been worked a good deal more than the others.

(a) Fuel economy. The tractor engine should make economical use of low-grade fuels. The compression ratio must be high enough to give good fuel economy, yet not so high as to cause pre-ignition. The volumetric efficiency must not be impaired by under-sized valves, or some such restrictions; the velocity in the intake manifold must, however, be high enough to maintain low-grade fuels in a vaporized form. The carburator must be short-coupled, as long manifolds tend to produce condensation. The shape of the combustion chamber should be such as to produce turbulence, which promotes rapid flame propagation and permits of the use of higher compression ratios. The cooling system should be so designed as to bring the temperature of the cooling water up quickly and to maintain it at or near 212 degrees Farenheit under all conditions; steam cooling would meet these demands particularly well.

(b) Mechanical efficiency. Mechanical losses in the machine may be reduced considerably by the use of ball and roller bearings and simple gear design. It is found however that the chief loss in transmitting the power of the engine to the drawbar occurs between the ground and the driving members. Wheel equipment has been given little study in the past, but in view of the great loss which occurs in the drive wheels this phase should be given special consideration.

2. Durability.

Proper proportioning of parts for strength and rigidity, good material, and good workmanship are essential to durability. These, however, must be accompanied by other features, as enclosure, good lubrication and replacement of wearing parts, all of which will be discussed separately.

3. Low Cost.

As the matter of cost is of such great importance, that item must constantly be kept in mind. In some cases desirable features must be ommitted for reasons of cost, but at all times the false economy of using poor materials and inferior workmanship should be avoided.

4. Simplicity.

The simpler a machine is the better, providing it accomplishes what is desired. Simplicity should be set up as one of the important criteria in tractor design, especially in view of the fact that the simpler machine is usually at the same time cheaper.

5. Accessibility.

The importance of accessibility in any machine is in direct proportion to the attention required. Conversely the accessible machine will be given more attention by the operator and therefore kept in better condition. Not only is time saved by having working parts accessible, but wear and breakages will be reduced because the machine will get better care. All parts requiring frequent attention, as the connecting-rod bearings and valves, should be readily accessible.

6. Protection of Working Parts from Dust.

Thorough enclosure of all working parts of a tractor is essential to long life. No machine of the same degree of refinement in construction works under as severe conditions as does the farm tractor, which is often driven through clouds of dust. The lubricant may easily be converted into a grinding compound of all dust is not excluded. An efficient air-cleaner is a very essential feature of any tractor.

7. Good Lubrication.

The film of oil, so essential between all parts that slide upon each other, must at all times be maintained and assured in order that wear and breakages may be reduced to a minimum. A lubricating system that does not require constant care is essential to the tractor.

8. Renewal of Wearing Parts.

All parts subjected to wear should be replaceable. For example, no wearing parts should be cast with the engine block unless the wear is likely to be very slight and not of serious consequence, as for instance the pushrod guides. Some important parts that should be replaceable are:

(a) Cylinder liners.

(b) Valve guides.

(c) Piston pin bushings.

(d) Camshaft bushings.

9. Operation.

The operator should be provided with a comfortable place to ride, where he is protected from the dust from the drivers, and the exhaust gases and heat of the engine. The machine should be easy to control and safe to operate.

10. Cultivating Attachment.

Cultivating rowed crops is one of the first requisites of the general-purpose tractor. This part of the equipment should therefore be an attachment for the tractor rather than a separate machine to be hitched on behind. This attachment should be of such size as to be in balance with other power requirements of the tractor, such as plowing.

11. Width of Track.

The distance between the wheels must be such as to fit the rows, so that the wheels will not run too close to the plants being cultivated. For plowing, a narrow track is desirable in order to avoid side draft. This should be considered in adapting the tractor to cultivating.

12. Clearance.

In order to decide upon the clearance necessary to work in fields of growing corn, a number of horse and motor-cultivators were measured. These have been known to give satisfaction, so that precedent may be safely followed in this respect. For horse-cultivators the average clearance seems to be about 30 inches, while one motor-cultivator was found to have only 25 inches. This is perhaps the minimum, but 28 inches would be ample clearance.

13. Size to Fit Practical Units.

It would be desirable to have all machines used with the general-purpose tractor of the same power requirements. This should be aimed at as near as possible in order not to overload the engine at some operations and run at only part load while performing others.

14. Unit Assembly.

Such parts as the engine and transmission may be built in separate units and mounted on a frame. This construction lends itself very well to efficient service work, as a defective unit may be easily replaced by another while the former is being repaired.

15. Speeds.

The tractive speeds of the tractor should be selected with care to fit the requirements of different machines. A large variety of speeds would be highly desirable. As the friction-drive is the only way with which this can be accomplished by purely mechanical means, with any degree of simplicity, it would seem better to use about three well selected speeds by gear drive.

16. Light Weight.

When traveling at a fairly high speed with a corresponding light drawbar pull, it is desirable to have light weight. When greater traction is required additional weight may easily be secured by adding extra weights. For this reason all efforts should be made to build a light weight machine.

17. Control.

Cultivating rowed crops requires quick and positive control in order that the plants may not be damaged. This control should be simple and easy to operate. The guiding should be entirely by the steering wheel and not partly by foot pedals.

18. Differential Brakes.

In order to turn in a small radius at the ends of the rows, differential brakes are almost essential, especially in soft ground where the front wheels tend to skid sideways. These should also operate by means of the steering wheel.

19. Power Take-Off.

The low efficiency of drive-wheels means that a great saving in power may be gained by driving harvesting machines, binders and corn huskers directly from the machine by a tumbling shaft rather than transmitting the power through two sets of wheels in contact with the ground. The direction and speed of the power take-off should conform with S. A. E. standards which have been adopted. The recommendation reads as follows: "The normal speed of the power take-off of tractors designed for operating tractor-propelled agricultural implements shall be 536 r. p. m., the rotation to be clockwise when looking in the direction in which the tractor travels."

20. Belt Pulley.

The position of the belt-pulley is very important from the standpoint of convenience in lining up with machines. The most desirable location for the belt pulley is at the side, preferably the right side, to be in best view for the operator. Often the pulley is placed so that the belt runs too close to some part of the tractor as the front wheel or front axle. The belt should run free from all obstacles.

21. Compact Arrangement.

A neat, compact arrangement of different parts is desirable, providing it is consistent with accessibility. For working in orchards it is particularly desirable that the tractor occupy as little space as possible.

22. Appearance.

Although not essential to utility, the matter of appearance should be given some thought by the designer. Simple, clear cut lines should be aimed at, partly for the sake of appearance, but also because it lends itself to economy in production.

## SECTION IV.

## THE DESIGN OF A GENERAL PURPOSE TRACTOR

Using the requirements set forth in the preceding section as a basis from which to work, the design of a machine to meet these requirements will now be undertaken. For information relating to calculations and standard practice in machine design the following references have been used:

1. Kent's Mechanical Engineer's Handbook.
2. The Gasolene Automobile, Volumes I and II, --Heldt.
3. Motor Vehicle Engineering, --Favary.
4. Machinery's Handbook.

1. Wheel Arrangement and Width of Track.

One of the first things that must be decided upon in the design of a general-purpose tractor is the wheel arrangement. A casual glance through one of the tractor journals shows what a variety of arrangements are used and which may be presented for consideration. A classification of types of tractors according to wheel arrangement might be made as follows:

1. Four wheel type, standard road track.
    (a) Rear wheel drive.
    (b) Four wheel drive.

2. Three wheel type, rear wheel drive.
    (a) Wide track, for cultivating, single steer wheel

in front.

(b) Single, wide drum for driving.

3. Two wheel type, front wheels drive, and steer.

4. Track type.

(a) Without steer wheels.

(b) Two steer wheels in front.

Before deciding upon the type of tractor, several important features must be considered. These will be discussed next.

II. Wheel Equipment.

In selecting wheel equipment, two possibilities are presented, the wheel type and the track type, or the "caterpillar" track, as it is commonly called. A drive wheel with lugs is cheaper to build than the track, but the latter has been found to be considerably more efficient, beside having the advantage of being able to pass over ground which is very wet and soft. The track has a large number of wearing parts, however, and will require repair and considerable attention. It is thought that the cheapness and long life of the wheel more than offsets the higher efficiency and the ability of the track to pass over all kinds of ground, when the choice of wheel equipment for a general-purpose tractor is involved. In many cases, when the land is too wet for the use of a light weight wheel tractor, it is unfit to be worked. For those reasons, the wheel type will be adopted for the proposed design.

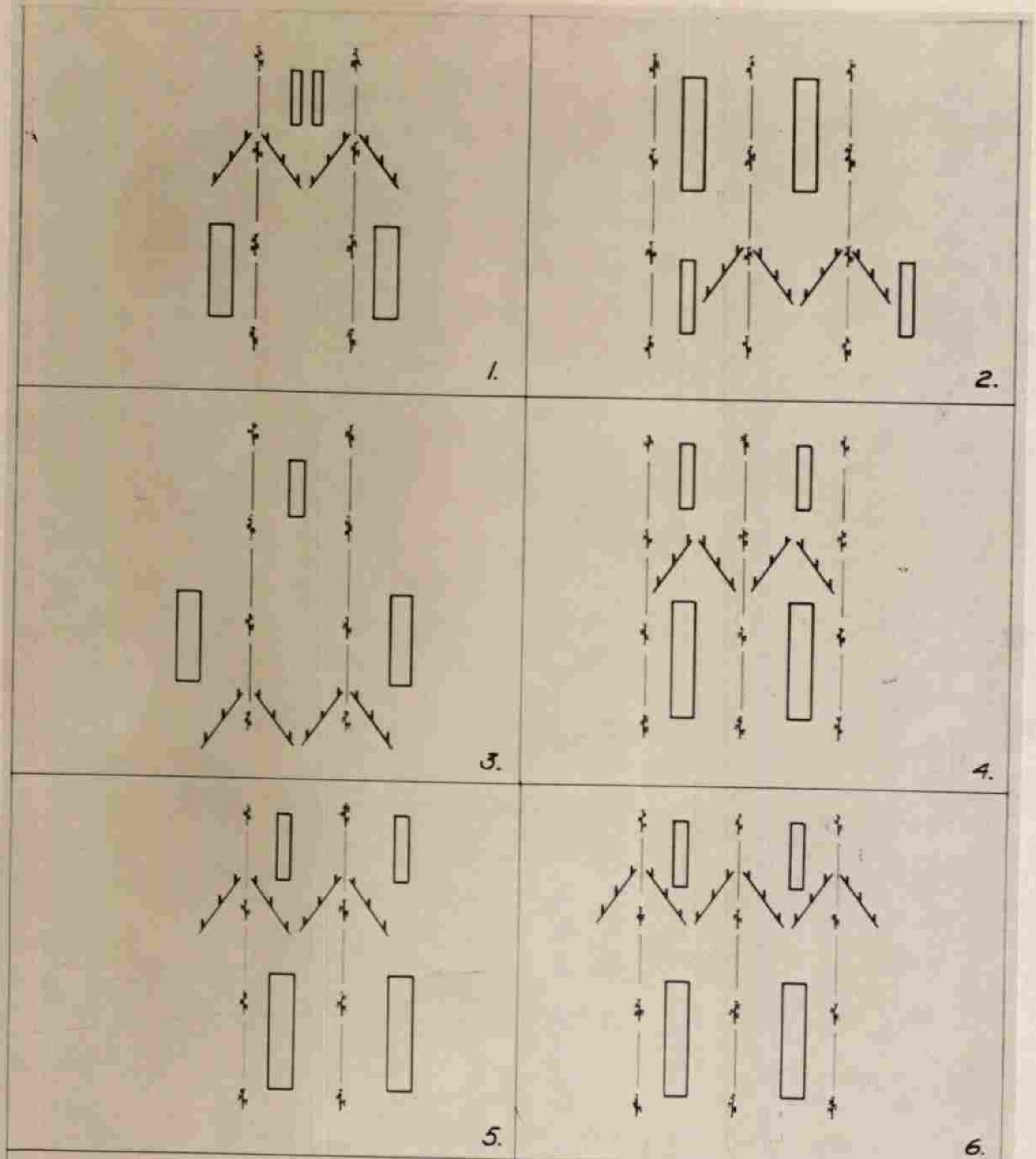
III. Possible Arrangements for Inter-Tillage.

As the cultivating attachment is one of the first requisites of the general-purpose tractor, and as this type of cultivator must govern, or be governed by, the wheel arrangement, the possible arrangements for inter-tillage will be considered next with a view of deciding upon the best type of tractor to design.

Figure I shows six possible arrangements, some of which are used on well-known general-purpose tractors and motor-cultivators.

No. I is an arrangement used by two different companies manufacturing general-purpose tractors. The tractor straddles two rows of corn. This arrangement fits in very naturally with the two row cultivator; no great difficulty is encountered in obtaining the necessary clearance, as the motor is in the center between two rows. Application to the two row cultivator however, is obtained at the expense of the most desirable wheel arrangement for plowing. The wide track is an objectionable feature when it comes to plowing with a one or two bottom plow as a certain amount of side-draft is inevitable. Steering also would be difficult when plowing, as one of the drivers runs in the furrow while the front wheels are on the land.

No. 2 is an arrangement that has been used on two makes of general-purpose tractors. Guiding is here a double operation; the tractor must be guided by the steering wheel while the gangs




Possible Arrangements for Inter-Tillage.

Fig. I

are guided by the use of the foot pedals. The two places so far removed cannot easily be watched at the same time, and guiding becomes a difficult operation. The side-draft is also objectionable with this arrangement.

No. 3 is used by at least two manufacturers of motor cultivators. The double control is also used in this case, and the wide track makes the tractor inapplicable to plowing.

In order that a tractor be suitable for plowing with two bottoms it must be narrow. Granting that plowing is the most important operation that the tractor must perform, it would seem reasonable to accept the arrangement of wheels best suited for that purpose, which is the four wheel, narrow track type, and try to fit it into the cultivating scheme. The four wheel type presents two possibilities, the four wheel drive and the rear two wheel drive. The former involves excessive mechanical complications and has been found more difficult to steer. It will then be discarded, in spite of improved traction, for much the same reasons as the track type was discarded. This limits the choice to the four wheel type, rear wheel drive.

Let us next consider possible arrangements of the conventional type, four wheel tractor for cultivating corn. No. 4, 5, and 6 present three possibilities. No. 4 possesses the undesirable feature that three rows have to be watched, or at least two, when a two-row planter is used. The guiding could be made more satisfactory with arrangement No. 5, but the side-draft would be objectionable. Owing to the difficulties in working out a satisfactory arrangement with two rows for this type of tractor a three-row scheme is suggested.

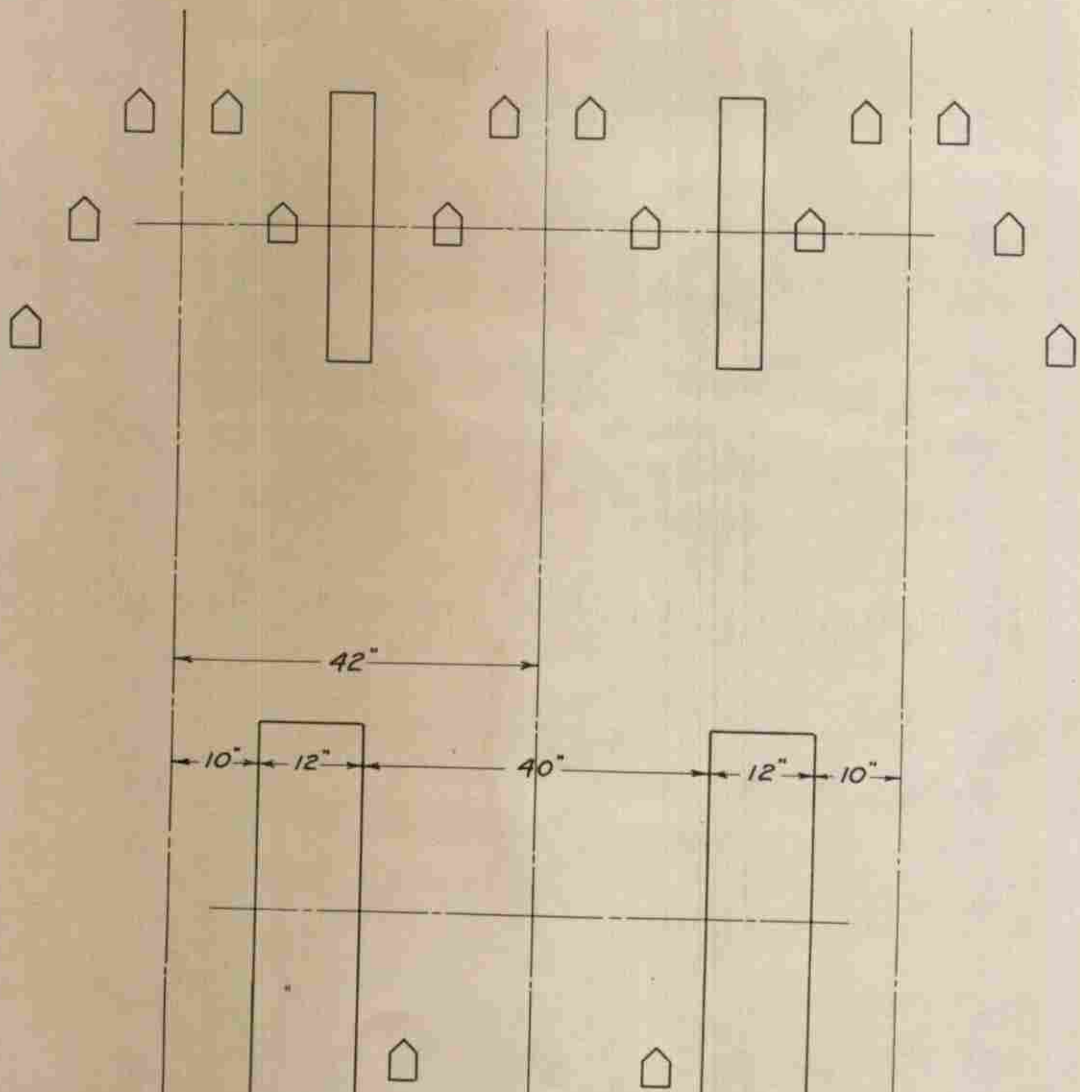
The advantages of the three-row arrangement shown in No. 6 over the two-row arrangements are:

1. Power requirements are more nearly those of a two bottom plow.
2. No side draft.
3. Work may be done more quickly.

The chief disadvantage of this scheme is that it would necessitate the use of a three-row planter. However, since the planter would likely be used with the same tractor an extra row would help to give it a reasonable load. The matter of obtaining the necessary clearance may also involve some difficulties.

Arrangement No. 6 has been selected as the most desirable scheme, and the arrangement of shovels has been proposed as shown in Fig. 2. By placing the shovels well ahead, quick control may be secured by simply operating the steering wheel. Foot pedals will be dispensed with and it will only be necessary to watch one of the outsdde rows when the rows are followed as planted; the other rows will register. The shovels which are in line with the drive wheels are placed behind in order that the wheel tracks may not be left packed.

An experiment conducted by Prof. E. V. Collins, of the Iowa State College Experiment Station, with a cultivator




Proposed Arrangement of Cultivator Shovels

Fig. 2

placed well ahead of the tractor as in this suggested arrangement, has convinced the writer of the advantages of the scheme, particularly as regards ease of control.

IV. Size of Tractor.

The size of the general-purpose tractor should be such as to be applicable to practical units of field and belt machines. It will not be possible to use all machines requiring the same amount of power, but that should be aimed at as an ideal. Plowing is the heaviest field work that it will be required to do. Nothing less than a two-furrow plow would be considered practicable. A three-furrow plow would require a larger tractor than would be practicable for cultivating corn.

A two-plow tractor will perhaps come nearest to being the right size for other practical units. Let us examine the draw-bar pull required by machines which would approximately fit the two-plow tractor.

TABLE XIV.

Drawbar Pull Requirements of Machines. (Approximate.)

| | | |
|---|---|---|
| 1. | Two-bottom plow, 6" deep in heavy clay soil | 1500 lbs. |
| | " " " " " " average soil. . | 1000 lbs. |
| 2. | Three row corn planter. . . . . . . . . . . | 900 lbs. |
| 3. | " " " cultivator . . . . . . . . . . | 900 lbs. |
| 4. | Double disk harrow. . . . . . . . . . . . . . | 1200 lbs. |
| 5. | Eleven-foot grain drill with harrow . . . . | 1000 lbs. |
| 6. | Ten-foot grain binder . . . . . . . . . . . | 800 lbs. |
| 7. | Corn picker . . . . . . . . . . . . . . . . | 1400 lbs. |

This gives a fairly good balance between different machines. If the tractor is designed to meet the conditions here given for a two bottom plow it will be large enough under most circumstances, yet, using the above machines it will never be required to work at such a light load as to materially lower its efficiency.

1. Horse Power Required at Draw-Bar.

Three miles per hour is a good working speed for plowing. With an average draft of 1000 lbs., this will require:

$$\frac{1000 \times 3 \times 88}{33{,}000} = 8 \text{ H. P.}$$

A lower speed of two miles per hour might be used for heavy plowing. With a maximum draft of 1500 lbs. this also would require 8. H. P.

It would seem that 9 H. P. would be ample to take care of the draw-bar work.

Relation between Drawbar and Brake H. P.

The rating of tractors is by no means standardized. It is common practice to use a drawbar H. P. rating which is 50% of the brake H. P. rating, but some manufacturers use 60% of the brake H. P. for the drawbar rating.

In order to get some idea ofthe relation that may be expected between drawbar and brake H. P. of tractors the following table was made up from results of the Nebraska Tractor Tests on 17 different makes of tractors of approximately the size under consideration.

TABLE XV.

Drawbar Efficiency of Tractors.
Compiled from Nebraska Tractor Tests.

| Engine | Rating | Max. Brake | H. P. Draw-bar | Ratio D.H.P. / B.H.P. | Rated Load H.P. Hrs. per gallon Br | Dr | Ratio Dr. / Br. |
|---|---|---|---|---|---|---|---|
| Allis Chalmers | 12-20 | 33.18 | 20.9 | .63 | 9.71 | 5.32 | .50 |
| Bates Stl Mule | 15-22 | 29.78 | 23.0 | .78 | 7.39 | 6.07 | .80 |
| Case | 12-20 | 25.54 | 17.0 | .67 | 10.10 | 5.40 | .54 |
| Cletrac | 12-20 | 24.94 | 15.52 | .62 | 8.33 | 5.04 | .60 |
| Eagle | 12-22 | 23.35 | 13.0 | .56 | 7.92 | 4.13 | .52 |
| Emerson B'ngham | 12-20 | 27.30 | 17.55 | .64 | 8.45 | 5.73 | .68 |
| Fordson | | 19.15 | 9.34 | .49 | 7.32 | 2.45 | .34 |
| Frick, Model A | 12-20 | 22.31 | 14.37 | .64 | 6.69 | 4.07 | .61 |
| Hart-Parr | 20 | 23.0 | 14.0 | .61 | 8.86 | 5.42 | .61 |
| Heider | 12-20 | 24.24 | 13.43 | .55 | 6.81 | 4.35 | .64 |
| Huber | 12-25 | 25.7 | 16.7 | .65 | 6.08 | 4.37 | .72 |
| Lauson | 12-25 | 37.38 | 20.9 | .56 | 8.53 | 4.64 | .54 |
| McCormick D'ng | 10-20 | 21.84 | 15.54 | .71 | 10.15 | 5.81 | .57 |
| Minneapolis | 12-25 | 26.24 | 15.73 | .60 | 6.71 | 3.80 | .57 |
| Oil Pull | 12-20 | 25.87 | 15.02 | .58 | 10.82 | 5.41 | .50 |
| Twin City | 12-20 | 27.93 | 18.43 | .66 | 7.88 | 5.00 | .63 |
| McCormick D'ng | 15-30 | 32.86 | 19.87 | .60 | 10.19 | 6.22 | .61 |
| Mean | | | | .62 | | | .59 |

The overall drawbar efficiency, or the ratio between drawbar and brake H.P. will depend upon the efficiency of the lug equipment and the efficiency of the transmission. In the above tables this has been figured in two ways: first, by dividing the maximum drawbar H.P. by the maximum brake H.P., and second, by dividing the H. P. hours per gallon at rated drawbar load by the H. P. hours per gallon developed on the brake, also at rated load. The mean of these ratios was found to be .62 and .59 respectively. This figure would represent the efficiency of the transmission and lug equipment under the conditions of the tests.

It must here be explained that these tests were all made ona cinder track, which is not a practical working condition, but would undoubtedly give a higher efficiency than would be obtained under average field conditions. According to recent tests conducted at Iowa State College, the efficiency of tractor lug equipment has been shown to be around 50%. In order to account for the losses in the transmission, the overall drawbar efficiency must then be somewhat below 50%.

It would seem therefore that the 60% rating, as often used, were too high. It is thought liberal, in view of present information, to use 50% as the overall drawbar efficiency.

2. Size of Engine.

Taking 9 H. P. as that required at the drawbar and .5 as the drawbar efficiency, the required brake H. P. would be 18. It is recommended that a reserve power of 20 to 25% be allowed. The size of engine suitable for this tractor would then be about 22 H. P.

V. Clearance.

With the proposed three-row cultivator arrangement, sufficient clearance must be allowed under the center of the tractor to pass over corn of considerable height without breaking it down. A clearance of 28 inches will be used in the preliminary layout. A small deviation from this will be permissable, if found necessary.

VI. Type of Engine.

The number of cylinders is one of the first questions that arises in the selection of an engine. Two and four cylinder engines are used for tractors; each type has its advantages. In favor of the two cylinder engine may be mentioned simplicity and good carburetion. Against these we have in favor of the four cylinder engine steadier power, less vibration and lighter weight. It is cheifly for the last reason that it is thought advisable to use a four cylinder engine in the general-purpose tractor.

VII. Engine Location and Arrangement.

The location of a four cylinder engine relatively to the reame, may be with the crankshaft lengthwise or crosswise. The former is the automobile type and the motor is placed vertically. When the crankshaft is crosswise with the frame, the motor may be either horizontal or vertical, according to practice in tractor design. The main objection to the latter arrangement is that when plowing with one drive in the furrow, the crankshaft is tilted, end thrust is set up which causes wear, and lubrication is impaired. Manufacturers building tractors of that type do not recommend plowing with one driver in the furrow. When using a two-bottom plow with a tractor it is best to run the right wheels of the tractor in the furrow, as otherwise considerable side draft is unavoidable.

1. Method of Obtaining Clearance.

It has been decided to have the motor placed with the crankshaft lengthwise with the frame and to plow with two wheels in the furrow. The problem now arises, how to obtain the necessary clearance of 28 inches in the center. The motor might be offset about 6 inches to one side, which would be a bad feature. A vertical motor in that position would necessarily be rather high; its center of gravity would be higher than would be desirable.

A horizontal engine might be used, and when so placed as to balance the crankshaft would be offset some distance to one side and a certain amount of clearance gained. In order to determine the amount of offset that would be permissible, it would be necessary to find the center of gravity of the particular engine in question.

2. Center of Gravity.

Some enginess were weighed in order to get an idea of the location of the center of gravity. From the results obtained it is safe to assume that the center of gravity of an engine of the required size would be approximately 4 inches from the crankshaft along the axes of the cylinders. An offset of 6 inches would therefore cause a slightly unbalanced condition. As it is felt that an offset of at least 6 inches would be desirable to obtain the necessary clearance, this figure will be adopted, at least tentatively. The degree of unbalance may better be determined later, but it is thought that this amount of offset will not have much detrimental effect.

3. Offset Horizontal Engine.

In some respects a horizontal engine is preferable to a vertical engine. Accessibility and low center of gravity are the main advantages. A probable danger of using the horizontal type in this way is the possibility of getting the cylinder head lower, when working on a side slope, with the result of fouling the combustion chamber with lubricating oil. This possibility should be guarded against.

4. The Inclined Type.

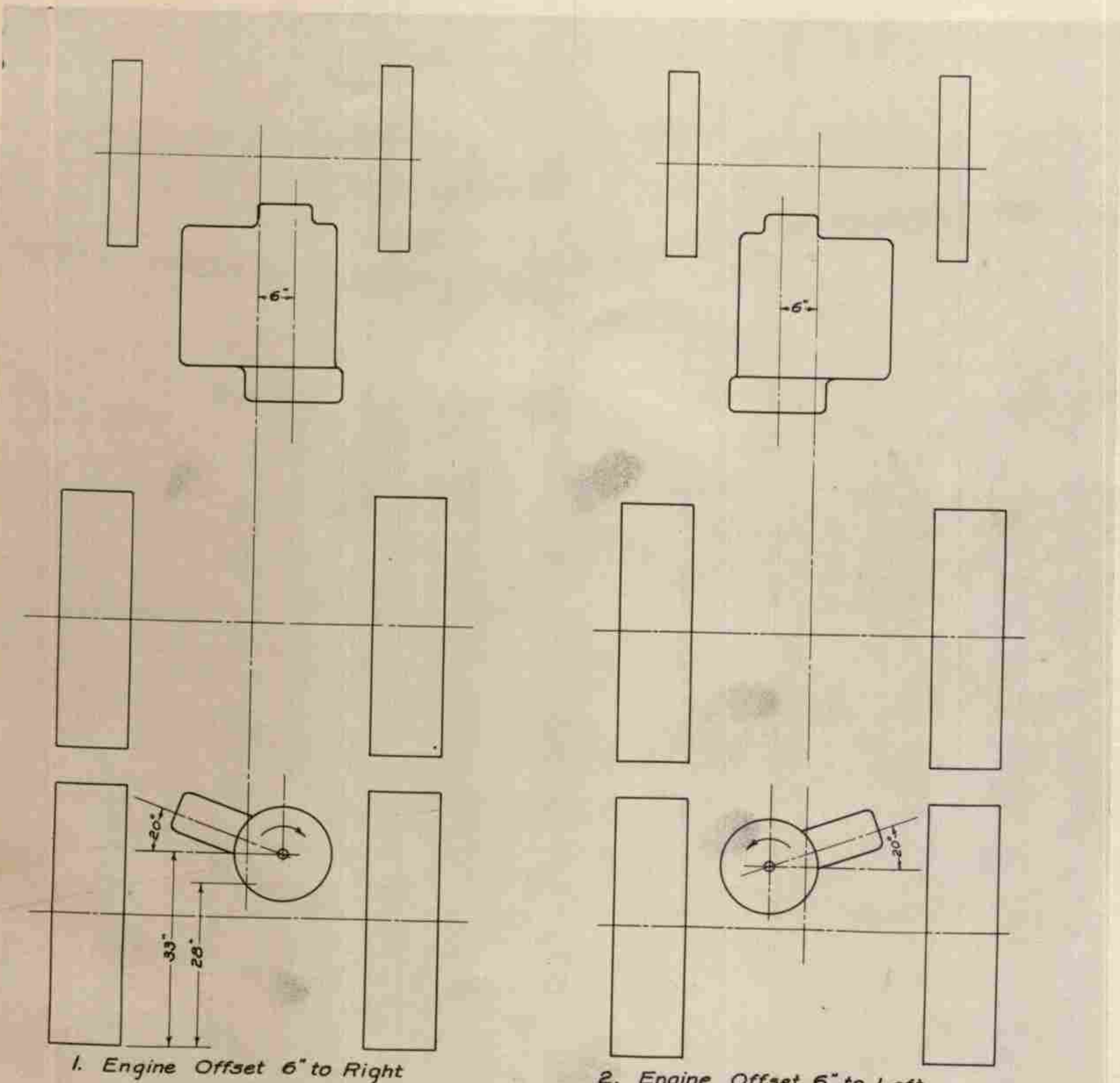
After giving due consideration to the horizontal engine it was conceived that by inclining the engine 15 or 20 degrees from the horizontal all the advantages of the horizontal type might be gained, and the possibility of fouling the combustion chamber would be avoided. With this arrangement, it might even be possible to lubricate the engine without force-feed to the cylinders - a feature not in use on horizontal engines.

5. Right or Left Offset.

Here arise two possibilities; the engine may be either offset to the left or to the right of the center line of the tractor. Fig. 3 shows these two arrangements. The direction of rotation should in either case be "over," as indicated by arrows, in order that the side thrust on the piston due to the angularity of the connecting-rod be downward where conditions are most favorable for good lubrication. When these two arrangements are compared, a number of advantages are found on both sides. These may be summed up as follows:

1. Engine offset on right:
   (a) Transmission on right, making control levers more convenient.
   (b) Belt pulley on right with a reasonable short shaft.
   (c) Hot part of engine on side ayay from operator.
2. Engine offset on left:
   (a) Engine cranks right-hand.
   (b) Power take-off runs in right direction with only one set of gears.
   (c) When plowing, the tilt tends to equalize weight on drivers.

After balancing up these points it has been decided that the latter is the better arrangement. It has therefore been adopted.




PROPOSED ENGINE ARRANGEMENTS

Fig. 3

VIII. Engine Design.

Preparatory to designing the engine, considerable thought was given to the transmission, in order to find out how this type of engine could be made to fit in with the general scheme of the tractor. After deciding upon the type of transmission, which will be discussed later, the actual design of the engine was undertaken.

1. Problem: To design a 4 cylinder engine capable of developing 22 B. H. P. on .6 to .7 lbs. of fuel per H. P. Hr.

2. Special Features Decided Upon.

(a) Engine inclined 20 degrees from horizontal.

(b) L type cylinder head.

(c) Ball bearing crankshaft - two bearing type.

(d) Steam cooling.

(e) Crankshaft speed 1,000 r. p. m.

3. Piston Displacement.

(a) Calculation on basis of assumed M. E. P. and mechanical efficiency

$$B.\ H.\ P. = \frac{NSS\ b^2 nP}{168,000}$$ . . . (90) Heldt Vol. 1, p 404.

N = number of cylinders . . . . . . . . . . . . . . . = 4

S = piston speed, feet per minute . . . . . . . . . $= \frac{n\ l}{6}$

b = bore - inches

n = mechanical efficiency . . . . . . . . .assume n = .85

P = M. E. P. during power stroke. . . . .assume P = 80

n = r. p. m . . . . . . . . . . . . . . . . . . . . . = 1,000

(90) becomes $\frac{N\ n\ l\ b^2 n\ P}{1,008,000} = B.\ H.\ P.$

Substituting, $\frac{4 \times 1,000 \times .85 \times 80\ l\ b^2}{1,008,000} = 22$

$$l\ b^2 = 81.5$$

Assume $l = 1,25b$

$1.25b^3 = 81.5$

$b = 4.02$

$l = 1.25 \times 4.02 = 5.02$

Piston displacement $= \frac{(4)\ (4.02)^2\ (5.02)}{4} = 256$ cu. in.

(b) Calculation of basis of fuel consumption:

R. P. M. = 1,000  H. P. = 22

No. of working strokes per min. = 2,000

Fuel per H. P. Hr. = .65 lbs.

Volumetric efficiancy, $E_v = .8$ (Carpent. and Diedricks page 86)

Air per lb. of fuel - assume 18 lbs.

Temperature of air at end of suction stroke, 100° F.(approx)

Air used per hr. $22 \times .65 \times 18 = 258$ lbs.

Air at 32° F. weighs .0807 lbs. per cu. ft.

Air at 100 F. weighs $\frac{491 \times .0807}{559} = .0709$ lbs. per cu. ft.

Air used per power stroke $\frac{258 \times 1728}{x8 \times .0709 \times 2,000 \times 60} = 65.4$ cu.in

Piston displacement = $4 \times 65.4 = 262$ Cu. In.

## 4. Cylinder Dimensions.

Suggested cylinder dimensions.

| Bore | Stroke | $\frac{\text{Stroke}}{\text{Bore}}$ | Displacement |
|---|---|---|---|
| 3 3/4 | 6 | 1.6 | 263 |
| 4 | 5 1/4 | 1.31 | 264 |
| 3 7/8 | 5 1/2 | 1.42 | 259 |
| 4 | 5 1/2 | 1.375 | 276 |

Any of the above would fill the requirements. There is probable some advantage in using even 4 inch bore. 4 X 5½ gives a good ratio of bore to stroke and the displacement is not too high.

Use 4 in. bore X 5½ in. stroke.

## 5. Compression Ratio.

$\eta_3 = 1 - (\frac{I}{r})^{.3}$ . . . . . . . . . . . (14) Heldt Vo.l.p.34.

Where $\eta_3 = \frac{Q_1 - Q_2}{Q_2}$ , Rankine efficiency

$r$ = compression ratio.

$\eta = \frac{\text{output}}{\text{input}} = \frac{33,000 \times 60 \times 100}{.65 \times 19,000 \times 778} = 20.6\%$

With this value for $\eta$, $\eta_3$ = about .35

Substituting in (14), $.35 = 1 - (\frac{1}{r})^{.3}$

$(\frac{1}{r})^{.3} \quad .65$

$$.3 \log. \frac{1}{r} = \log. 65$$

$$\frac{1}{r} = .237$$

$$r = 4.2$$

6. Volume of Compression Space.

Let $V_1$ = vol. on head center.

" $V_2$ = " " crank " .

Then $\frac{V_2}{V_1} = 4.2$ and $V_2 = 4.2 V_1$

$V_2 - V_1 = 69$ cu. in. (displacement of one cylinder)

$V_1 = V_2 - 69$

$V_1 = 4.2V_1 - 69$

$3.2 V_1 = 69$

$V_1 = 21.56$ Cu. in.

7. Cylinders.

It was decided to use removable cylinder liners.

Cylinder wall thickness, $t = \frac{b}{30} - \frac{1}{8}"$ . . (32) Heldt Vol.1.p83

$t = \frac{4}{30} + \frac{1}{8}$ .258"

Let thickness of cylinders and water jacket $= \frac{1}{4}"$

8. Cylinder Head Studs.

Use $\frac{1}{2}"$ studs for 4" bore - Favary, p. 39.

Drill $\frac{7}{16}$, thread $\frac{1}{2}"$

9. <u>Crankshaft.</u>

For a two bearing, four cylinder crankshaft the dimensions of the main parts may be determined by the following formulae from Heldt Vol. 1, p. 192.

D = displacement of one cylinder.

d = diameter of connecting rod bearings.

l = length of " " " .

w = width of crank arms.

$t_s$ = thickness of short crank arms.

$t_l$ = thickness of long crank arms.

$d = \left(\frac{D}{12.5}\right)^{\frac{1}{2}}$ . . . . . . . . . . . . . . . . (71)

$d = \left(\frac{69}{12.5}\right)^{\frac{1}{2}}$ . . . 2.35. Use $d = 2\frac{1}{2}$" and $l = 2\frac{1}{2}$"

$w = 1.25\ d$ . . . . . . . . . . . . . . . . (72)

$w = 1.25 \times 2.5 = 3.12$. Use $w = 3\frac{1}{2}$".

$t_s = .55 \left(\frac{d^3}{w}\right)^{\frac{1}{2}}$ . . . . . . . . . . . . . . (73)

$t_s = .55 \left(\frac{(2.5)^3}{3.5}\right)^{\frac{1}{2}}$ 1.16. Use $t_s = 1\frac{1}{4}$"

$t_l = .8 \left(\frac{d^3}{w}\right)^{\frac{1}{2}}$ . . . . . . . . . . . . . . . (74)

$t_l = .8 \times 2.1 = 1.7$. Use $t_l = 1\frac{3}{4}$"

Deflection in circular shafts $= K \frac{l}{(d^4)}$

Ratio of deflection of $2\frac{1}{2}$" shaft to deflection in 2.35" shaft $\frac{(2.35)^4}{(2.5)^4}$ .78, or 22% less than in shaft figured by (71)

10. Crankshaft Bearings.

Explosion pressure $= \frac{\pi}{4} \times 4^2 \times 400 = 5{,}000$ lbs.

Assuming this pressure to occur on one main bearing, which is on the side of safety, a bearing from New Departure data sheet was sèlected.

Bearing No. 1316, capacity 4,985 lbs. at 1000 r. p. m. was selected.

Rear main bearing is held in place by a collar which is secured by six 3/8" cap screws. This collar also forms part of the flywheel housing. All end thrust is therefore taken up on the rear bearing, while the front bearing is allowed to move freely endwise to allow for expansion in crankshaft.

11. Connecting Rods.

The ratio of length of connecting rod, l, to stroke, s, varies from 1.75 to 2.5 in practice. If $l = 13"$, $\frac{l}{s} = \frac{13}{5.5} = 2.36$, which is a fairly long rod. Let $l = 13"$

The thickness of web, t, was obtained from Chart III, Heldt, Vol. I, p. 220. If $S = 16{,}000$ lbs. per sq. in., $t = 2.05$.

Other dimensions were also obtained from Chart III.

Width of flange = .78"

Depth of I beam = 1.17"

Allow 3/16 in. for babbitt.

12. Piston and Rings.

(a) Length of piston, $l_p = 1.3\ b$ . . . Heldt, Vol. 1, p.153

$l_p = 1.3 \times 4 = 5.2$. Use $l_p = 5\ 1/4"$.

(b) Piston pin location was computed by (50) H.P. 156.

Locate piston pin $2\ \frac{15"}{16}$ below top.

(c) Width of rings.

$w = \frac{b}{20}$ . . . . . . . . . . . . . . . . . .(43) H. p.132.

$w = \frac{4}{20} = .2$. Let $w = \frac{7"}{32}$

(d) Thickness of rings.

$t = \frac{b}{27.5}$ . . . . . . . . . . . . . . . . .(41) H.,p.128

$t = \frac{4}{27.5} = \frac{5}{32}$

(e) Location of rings.

Width of top land $\frac{3"}{8}$ and other lands $\frac{11"}{64}$

(f) Piston head thickness.

$t_n = .032\ b + .06"$ . . . . . . . . . . .(51) H., p. 157

$t_n = .032 \times 4 + .06" = .188"$ Use $\frac{3"}{16}$

(g) Piston wall thickness.

At grooves, $.062\ b + .1" = .348"$ . . .(53) H., p. 157

At bottom, $.2\ b + .05" = .13"$ . . . .(54) " "

(h) Piston pin. High carbon steel.

$d = \frac{bp}{1600}$ . . . . . . . . . . . . . . . . (47) H., p.145

$d = \frac{4 \times 400}{1600} = 1"$. Outside diameter.

$d_1 = \left(d^4 - \frac{d\ b^3 p}{25}\right)^{\frac{1}{4}}$

12. $d_1 = \left(1 - \frac{4^3 \times 400}{2 \times 20{,}000}\right)^{\frac{1}{4}} = .77$. Use $\frac{3}{4}$" inside diameter.

13. Size of Valves.

Allow velocity through valve port of 7,000 ft. per min.

Piston speed, $\frac{1{,}000 \times 2 \times 5.5}{12} = 916$ ft. per min.

If $V_v$ = valve port velocity

$V_p$ = piston velocity

$d$ = diameter of valve.

$b$ = cylinder bore,

Then $\frac{V_p}{V_v} = \frac{d^2}{b^2}$ or $d^2 = \frac{V_p b^2}{V_v}$

$d^2 = \frac{916 \times 4 \times 4}{7{,}000}$ $d = 1.45$

Use $1\frac{1}{2}$" valves.

14. Valve Dimensions. . . . . . . . . . . . . . . . .Heldt, Vol.1,p.242

O. D. of head 1.15 d = 1.725" . . . . . . d 1.5"

Thickness of head.15 d = .225" (at center)

Stem diameter, .15 d + .15" = .375"

Radius of fillet .2 d = .3"

Valve lift, $h = \frac{d}{8} - \frac{1}{8}" = \frac{5}{16}"$

Let $H = \frac{3}{8}"$

15. Cams.

Use mushroom cam follower, (simple and cheap)

Period of inlet valve opening, 200 degrees.

Valve lift, l, = $\frac{3}{8}$"

A mushroom follower cam was designed.

$$D = l + R_1 - r$$

$$D \cos \frac{\phi}{2} = R_1 - r \quad \ldots\ldots\ldots \text{ Heldt, Vol. 1, p.259}$$

Where $\phi$ = period of valve opening.

$R_1$ = radius of base circle.

$r$ = radius of rounding circle.

$D$ = center distance of $R_1$ and $r$.

$$R_1 = r + l \frac{\cos \frac{\phi}{2}}{1-\cos \frac{\phi}{2}} = r + \frac{3}{8}\left(\frac{.64}{1-.64}\right) = r - .666$$

Let $R_1 = \frac{3}{4}$"

Then $r = .75 - .666 = .084$"

$$D = \frac{3}{4} + \frac{3}{8} - .084 = 1.091$$

16. Valve Springs.

Assume racing speed of engine 1400 r. p. m.

Assume weight of reciprocating parts, W = $1\frac{1}{2}$ lbs.

$$F = \frac{W D}{12 g}\left(\frac{2\pi N}{60}\right)^2 \quad \ldots\ldots \text{ Heldt, Vol. 1, p. 262.}$$

Where N = r. p. m. of camshaft.

F = force of acceleration at full lift.

$$F = \frac{1.5 \times 10091}{12 \times 32.2}\left(\frac{700\pi}{30}\right)^2 = 31 \text{ lbs.}$$

Use F = 40 lbs.

(a) <u>size of wire.</u>

$W = \frac{S\ d^3}{8\ D}$ . . . . . . . . . (90A) Heldt, Vol.I,p.270.

$d^3 = \frac{8\ W\ D}{\pi\ S}$

Where d = diameter of wire in inches.

W = maximum safe load in lbs.

S = Safe fiber stress;(use S = 50,000 lbs. per sq. in)

D = diameter of coil. Let D = 1 inch.

Substituting, $d^3 = \frac{8 \times 40 \times 1}{50{,}000\pi} = .00204.$

$d = .126$

Use No. 11 wire, d = .12.

(b) <u>Number of coils in spring.</u>

$F \quad \frac{8\ n\ P\ D^3}{E\ d^4}$ . . . . . . . (90B) Heldt, Vol.I, p.270.

$n = \frac{F\ E\ d^4}{8\ D\ D^3}$

Where n = number of coils.

P = difference in spring pressure with valve opened and closed.

F = amount of deflection in inches valve lift.

E = modulus of elasticity in shear, 12,000,000.

Substituting,

$n = \frac{.375 \times 12{,}000{,}000\ (.12)^4}{8 \times 6 \times 1^3} = 14.5$

Use a 14 coil spring.

Let length of spring when compressed = 3 inches.

Initial compression = $\frac{28}{6} \times \frac{3}{8} = 1\frac{3}{4}$ inches.

Free length of spring $3 + 1\frac{3}{4} = 4\ \frac{3}{4}$ inches.

17. Gears.

1. Cam Gears.

Using a template of the connecting rod to determine clearance, the minimum center distance of the camshaft and crankshaft was found to be 6.2".

Let $D_1$ = pitch diameter of crankshaft gear.

" $D_2$ = " " " camshaft " .

$D_1 + D_2 = 12.4"$

$2\,D_1 = D_2$, $\frac{3}{2} D_2 = 12.4$ $\quad D_2 = 8.26$

$$\begin{array}{r} D_1 = \underline{4.14} \\ 12.40 \end{array}$$

Using diametral pitch of 8 and helix angle 20 degrees,

$N_1 = D_1 P \cos 20^\circ = 4.13 \times 8 \times .94$ say 32 teeth.

$N_2 = 64$ teeth.

$$D_1 = \frac{32}{8 \times .9397} = 4.2567"$$

$$D_2 = 2\,D_1 = \underline{8.5134}$$

$$12.7701$$

Center distance = 6.385

2. Oil Pump Gears.

The matter of getting clearance between the cams for the oil pump gears involved some difficulty which may be seen by referring to Fig. 5 on page

Let diametral pitch = 12.

Let helix angle = $45^\circ$

Let number of teeth on camshaft = 19, then

pitch diameter of camshaft gear = $\frac{19}{12 \times .707} = 2.235$

Maximum pitch diameter of pump gear = 1.7"

Number of teeth in pump gear $= 1.7 \times 12 \times .707$ say 14.

18. Lubricating System.

With this type of engine it is thought possible to lubricate without force feed to the cylinders, as the angle of the cylinders would allow opportunity for surplus oil to drain back into the crank case. A circulating splash system is suggested, using a gear oil pump driven from the cam shaft as shown in Fig. 5 on page 94. The pump, according to this design, is bolted on the cover at the bottom of the pump, and would be removed along with its drive shaft when the cover is removed.

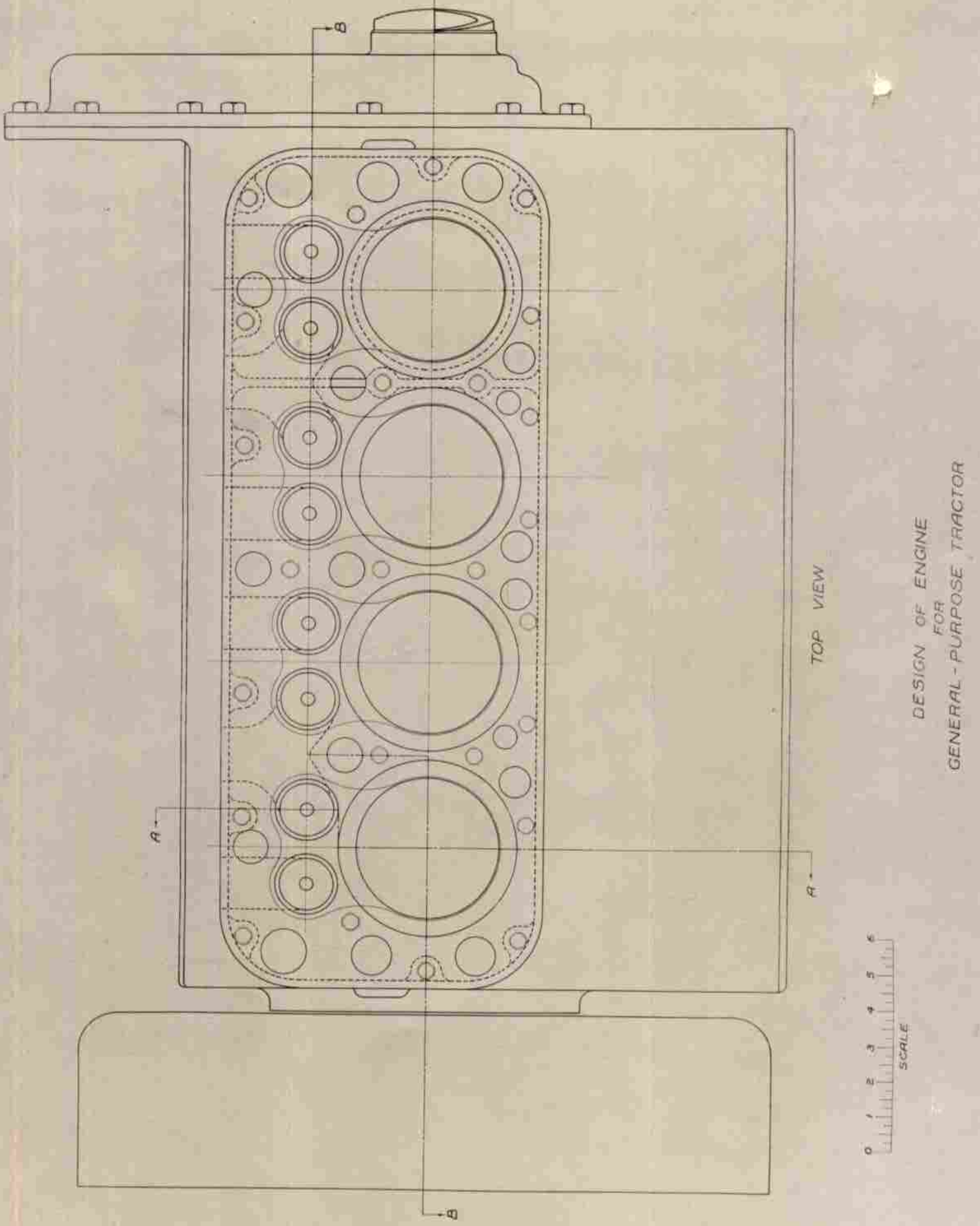
19. Flywheel and Flywheel Housing.

Outside diameter of flywheel, 17 inches.

Flywheel housing, - S. A. E. No. 2.

20. Engine Drawings.

On the following pages will be found assembly drawings of the engine. Fig. 4 is a top view of the engine block showing the arrangement of valves and location of studs. Fig. 5 is a vertical cross-section through the fourth cylinder, viewed from the front. Fig. 6 is a cross section on the plane of the center lines of the cylinders, showing part side elevation. Fig. 7 is a front end view of the engine showing pitch circles of timing gears and auxiliary shaft gear for driving magneto and governor.



B
A
A
B
TOP VIEW
DESIGN OF ENGINE
FOR
GENERAL-PURPOSE TRACTOR
0 1 2 3 4 5 6
SCALE


Fig. 4

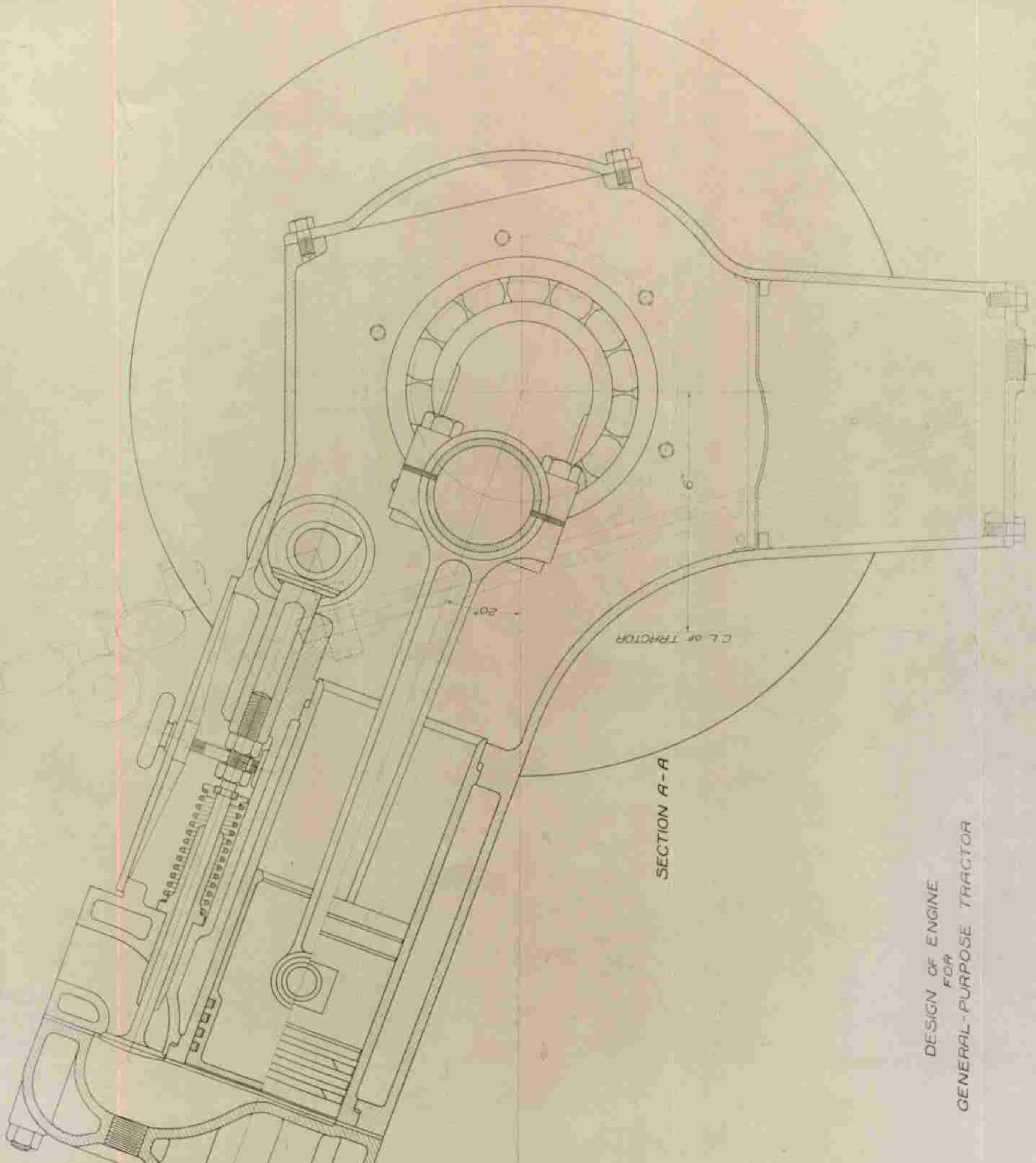

SECTION A-A
C.L. of TRACTOR
20°
6"
DESIGN OF ENGINE
FOR
GENERAL-PURPOSE TRACTOR

Fig. 5

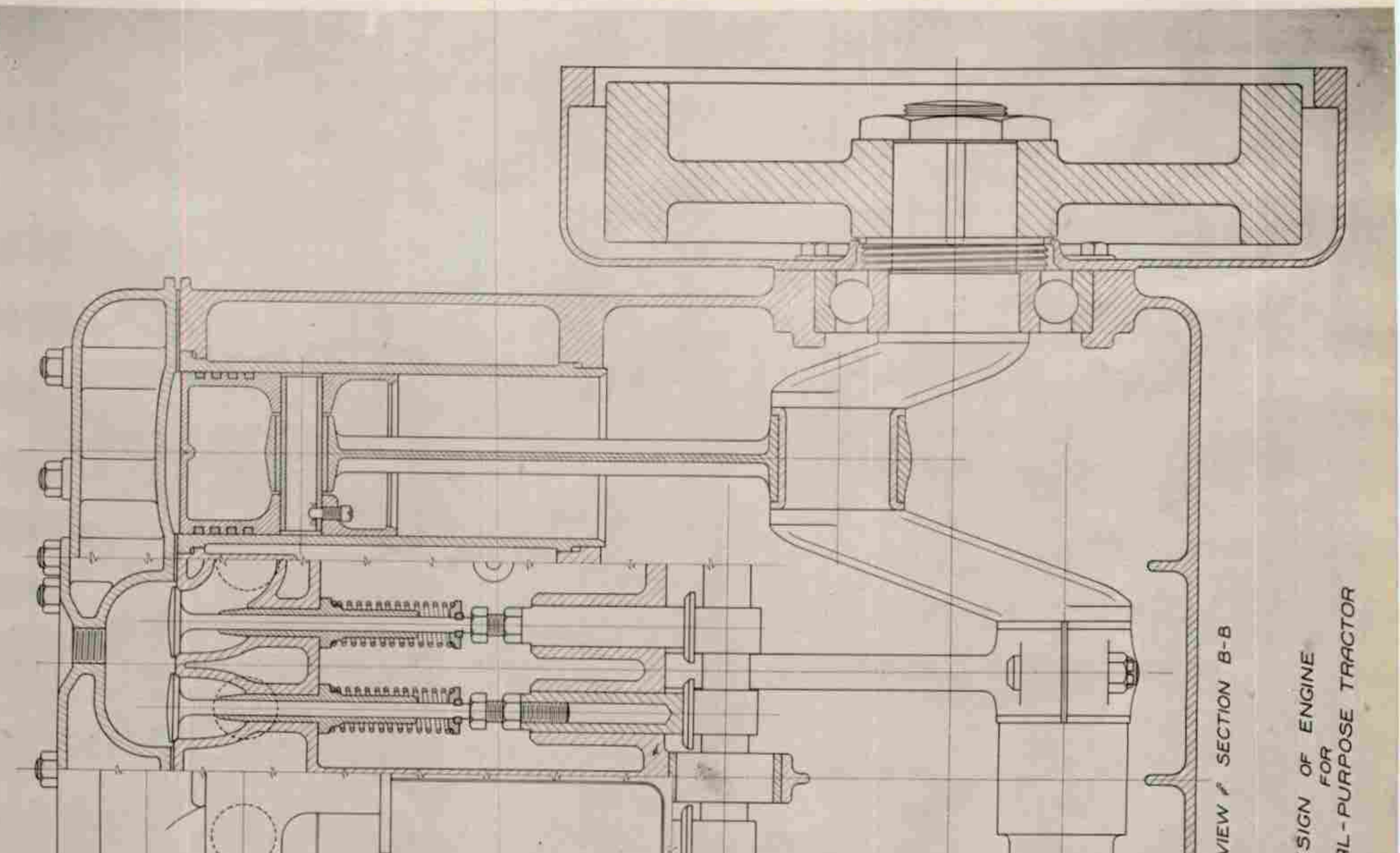

SIDE VIEW & SECTION B-B
DESIGN OF ENGINE
FOR
GENERAL-PURPOSE TRACTOR
SCALE

Fig. 6

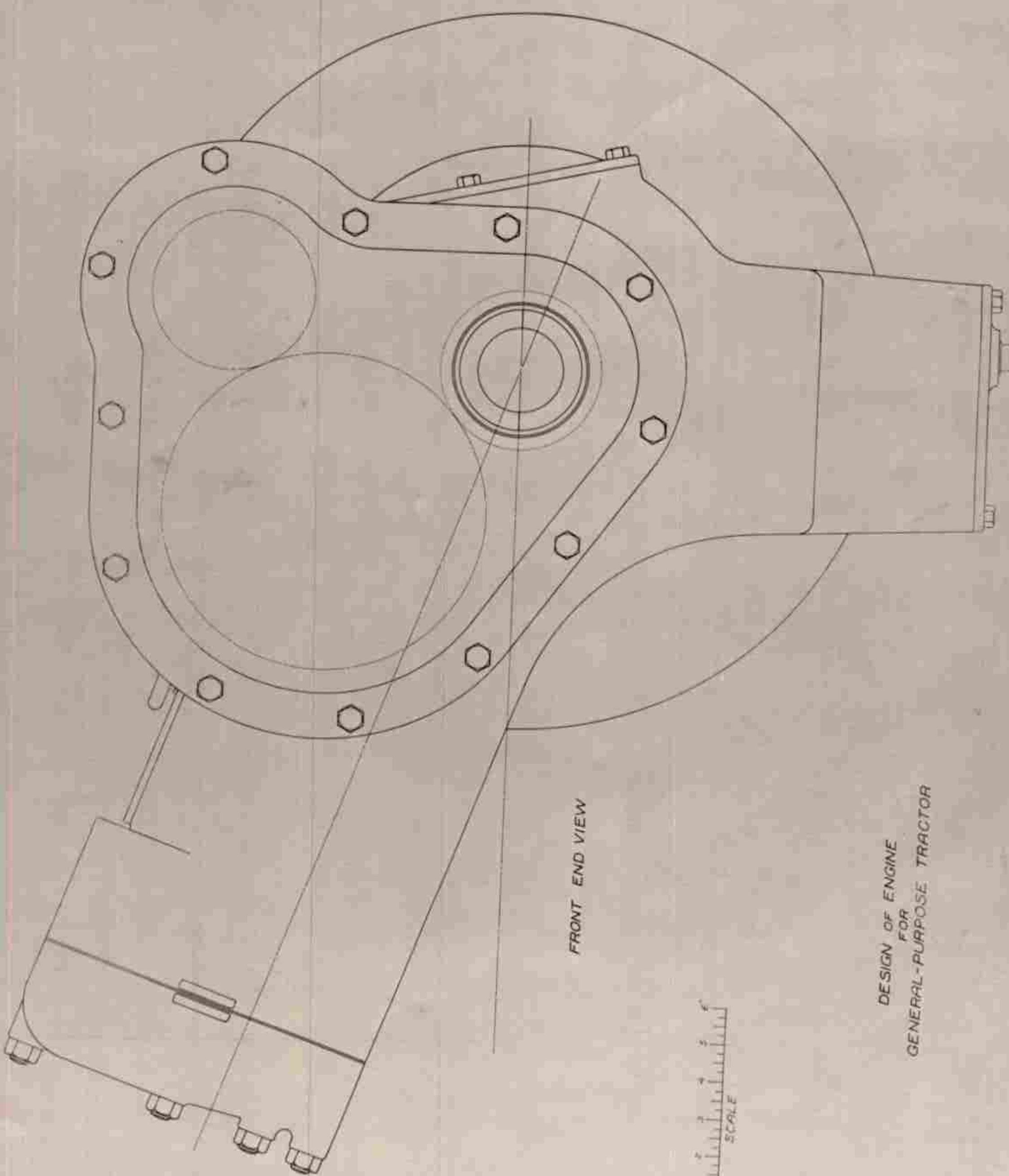

FRONT END VIEW
DESIGN OF ENGINE
FOR
GENERAL-PURPOSE TRACTOR
SCALE

Fig. 7

## IX. Transmission Design.

### 1. Type of Transmission.

A three speed forward and reverse, gear transmission has been selected. In order to obtain the necessary clearance under the rear axle it will be necessary to use stub-axles and two master gears for the final drive.

### 2. General Layout of Transmission.

It was thought at first that on account of the engine being offset to one side, the weight distribution might be corrected by placing the transmission on the opposite side. With this in mind Transmission No. 1 shown in Fig. 8 was laid out for consideration. The sliding change speed gears are placed in the center, while the differential is placed on the opposite side from the engine. An extra set of bevel gears is required, and a transverse shaft, in order to transmit the power from one side to the other. It is doubtful whether the advantage of weight distribution offsets the disadvantage of the mechanical complications which are involved with this arrangement.

Transmission No. 2, also shown in Fig. 8, is a simpler arrangement. In spite of imperfect weight distribution, this is thought to be the most satisfactory scheme.

### 3. Gear Shift Arrangements.

In the gear shift arrangements shown in Fig. 8 the sliding gears are on the countershaft*. This makes a very simple

* According to S. A. E. standard nomenclature, this shaft, which corresponds with the lower shaft in automobile transmissions, sometimes known as the secondary shaft, will be referred to as

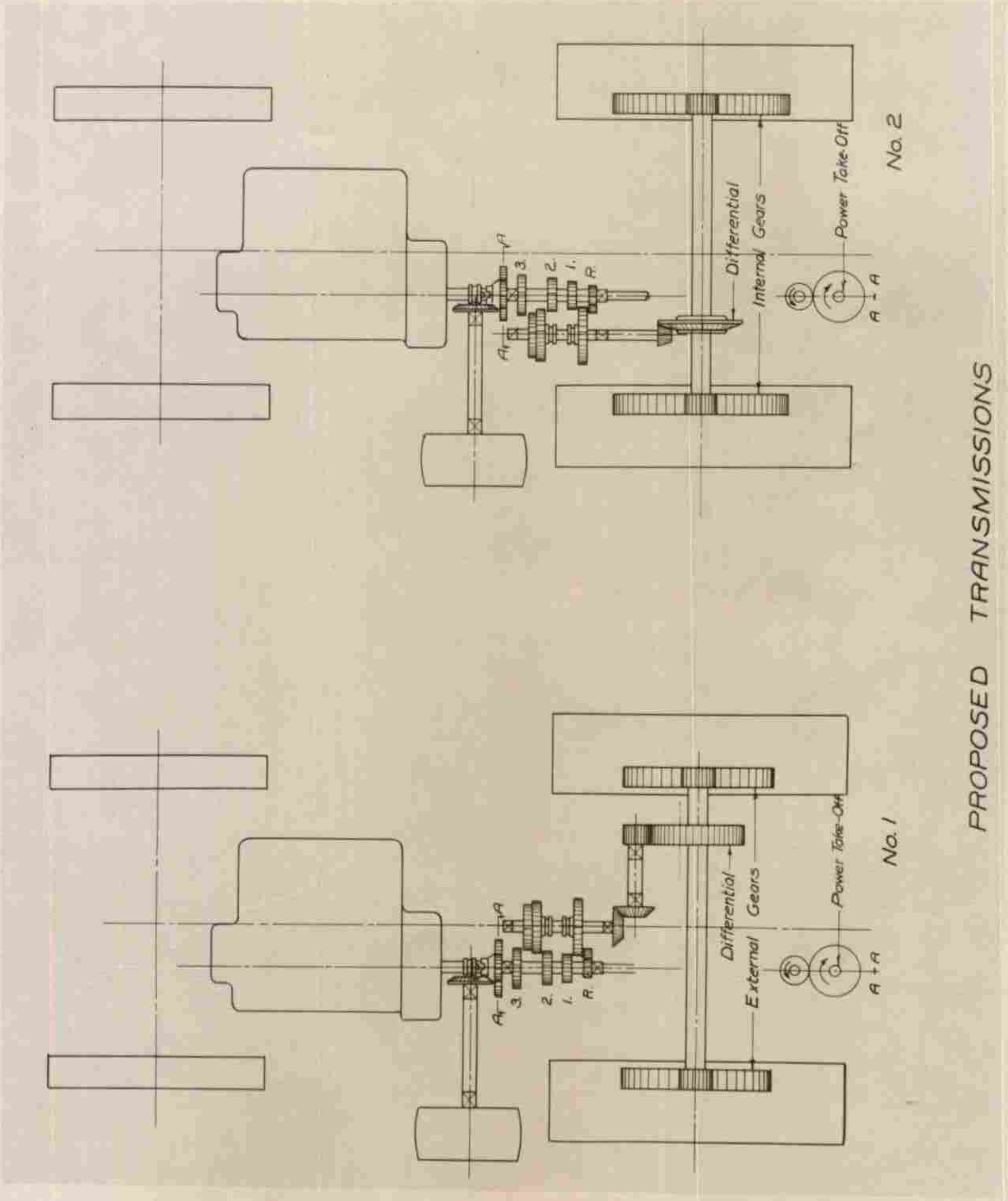

PROPOSED TRANSMISSIONS
No. 1
Differential
External Gears
Power Take-Off
A - A
No. 2
Differential
Internal Gears
Power Take-Off
A - A

Fig. 8

Arrangement. Requiring only a single reverse idler, but it has the disadvantage of sliding the larger gears, which are more apt to bind on the shaft than smaller ones. For this reason it was not given further consideration.

In sliding the smaller gears upon the transmission shaft** the chief difficulty is to obtain a simple reversing mechanism possessing other desirable features. The simplest arrangement always results in a high speed reverse idler.

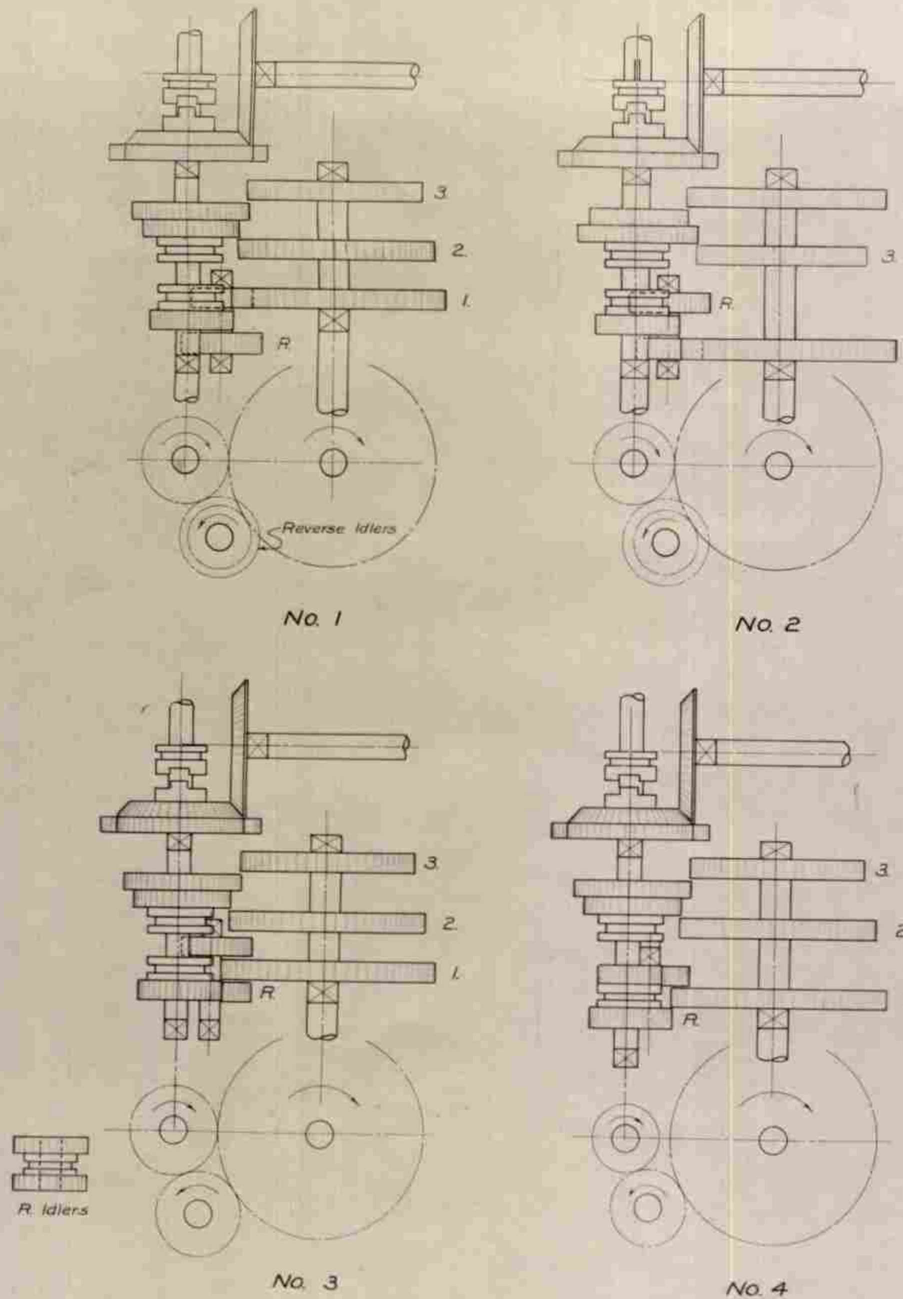
Fig. 9 shows four different gear shift arrangements. In no. 1 the low and intermediate gears are placed near the center of the transmission shaft, causing greatest bending moment in the shaft at ordinary working speeds but almost equal distribution of load upon the bearings. In No. 2 these gears are placed right up against the bearings, producing the least possible bending moment in the shafts, but most of the load is carried on one bearing. This arrangement also requires a longer countershaft. Of these two arrangements No. 1 is considered the better.

No. 1 and 2 are provided with rather a simple reversing mechanism. The constantly meshed idler pinion, which meshes with the low gear, is sufficiently smaller to allow the shifting pinion to clear it when in the low speed position. This would give a reverse speed lower than low speed forward by the same ratio as the numbers of teeth in the respective reverse idlers

---

the countershaft in subsequent pages.

** Sometimes known as the spline shaft in automobiles.




GEAR SHIFT ARRANGEMENTS

Fig. 9

which is not objectionable. This arrangement, though simple, has one outstanding objection, which is the fact that the reverse idlers are driven from the countershaft in direct ratio with the forward speed of the tractor, so that in intermediate or high speed, the pitch line velocity of these pinions would be quite high.

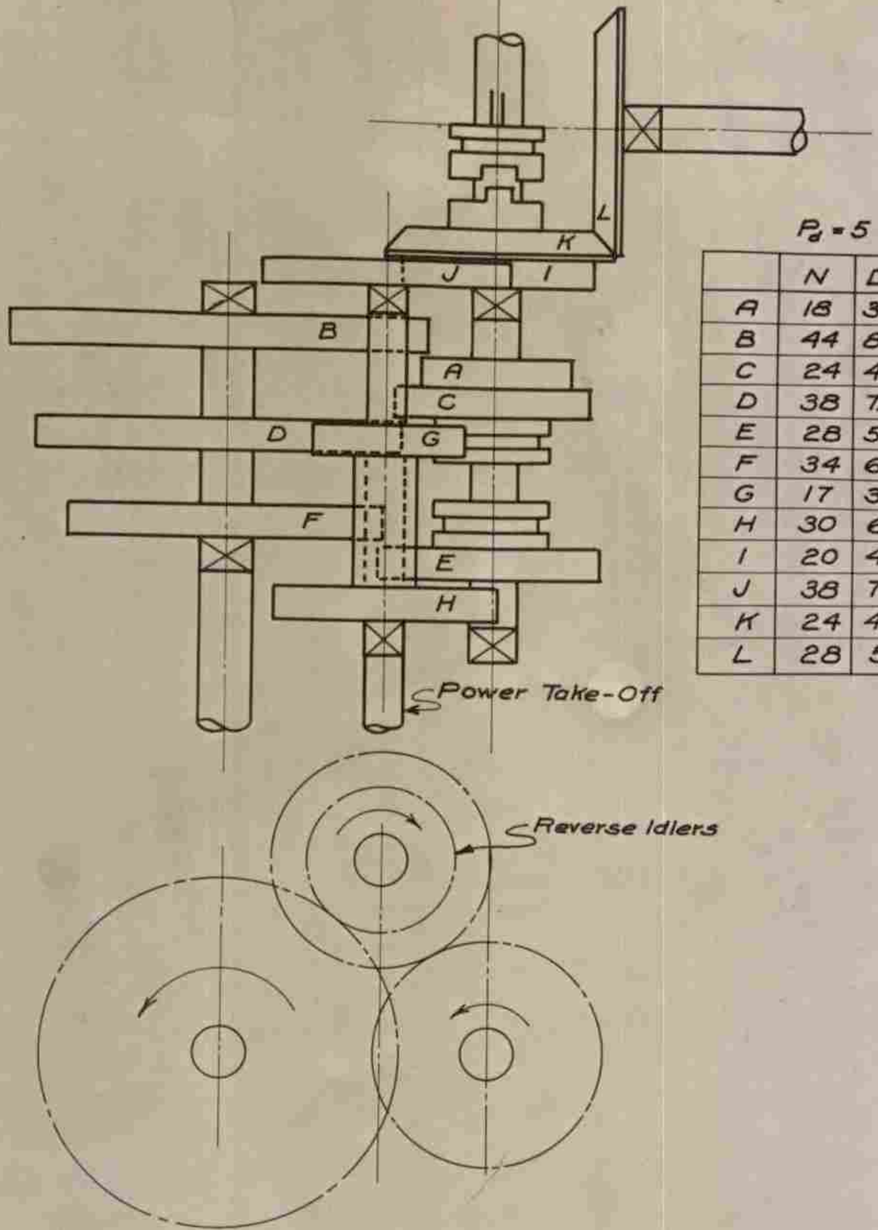
No. 3 and 4 are results of attempts to overcome the difficulty of high speed reverse idlers, both of which arrangements introduce mechanical complications. No. 3 has two reverse idlers of the same size, one of which is meshed with the low speed pinion at all times except when in low gear, when it is disengaged and the idlers would not rotate. When in reverse, the idlers both slide backward on the shaft with the low speed pinion, one of them remaining in mesh with the pinion while the other meshes with the low gear. The matter of sliding the reverse idlers when shifting to reverse while letting it remain stationary when shifting into low would involve mechanical difficulties which were thought too serious to warrant further consideration.

No. 4 introduces a sliding reverse idler which is positive in its relation to the low speed pinion, and which is in constant pinion. This arrangement accomplishes the desired effect of obtaining a low speed reverse idler. An extra shifting collar on the reverse idler so arranged as to slide with the low speed pinion, whatever its position, would make the shifting fairly simple. The fourth sliding pinion, however, would necessitate longer shafts and as its diameter would necessarily be smaller than that of the low speed pinion by at least twice the tooth depth, in order to clear the low gear, the diameters of all the other pinions and gears would have to be governed by its size. The low speed pinion would ordinarily be made as small as possible, consistent with the size of the shaft, and other gears designed according to its size. These objections to No. 3 and 4 led on to other attempts to overcome the difficulty of high speed reverse idlers.

4. <u>The adopted Gear Shift Arrangement</u>.

The process of shifting the gears would be more natural, it would seem, if the low and intermediate gears were on the same shift, as these are the ordinary working speeds. Using a common sliding pinion for high speed and reverse would make it possible to drive the intermediate gear to obtain the reverse motion. The advantage of this would be to obtain a lower pitch line velocity for the constantly meshed reverse idler, as in forward speed it would be driven from the intermediate gear instead of from the low gear. To have the constantly meshed idler pinion in mesh with the high gear would still further reduce this pitch line velocity, but this would require a larger reduction between the two reverse idlers than would be practicable.

Fig. 10 shows this arrangement, which has been adopted as the best of those yet considered.




$P_d = 5$

| | N | D" |
|---|---|---|
| A | 18 | 3.6 |
| B | 44 | 8.8 |
| C | 24 | 4.8 |
| D | 38 | 7.6 |
| E | 28 | 5.6 |
| F | 34 | 6.8 |
| G | 17 | 3.4 |
| H | 30 | 6.0 |
| I | 20 | 4.0 |
| J | 38 | 7.6 |
| K | 24 | 4.8 |
| L | 28 | 5.6 |

THE ADOPTED GEAR SHIFT

Fig. 10

5. Tractor Speeds.

The following speeds have been selected for the proposed general-purpose tractor:

| | | | | |
|---|---|---|---|---|
| High . . . . . . . . . . . | 4 miles per hour. | | | |
| Intermediate . . . . . . . | 3 | " | " | " |
| Low . . . . . . . . . . . | 2 | " | " | " |
| Reverse . . . . . . . . . . | 2 | " | " | " |

6. Probable Slip.

In calculating the gears, due allowance must be made for the slip of the drivers. According to the Nebraska Tractor Tests which are conducted on a cinder track, the average slip for all types of tractor lugs has been found to be about 10%. Under field conditions the slip w uld be considerably greater. According to recent investigations carried on by Mr. J. F. Goss and Mr. R. W. Baird at Iowa State College, it would seem reasonable to take 15% as the probable slip.

7. Reduction in Low Gear.

At 2 miles per hour with 15% slip a 46 inch drive wheel must make $\frac{2 \times 88 \times 12}{46 \times .85} = 17.2$ r. p. m.

The total reduction is then $\frac{1,000}{17.2}$ or 58.2 to 1, which must be divided between the sliding gears, the rear axle bevel gear, and the final drive. It would be desirable to get as much reduction as possible in the first reduction. Assuming a low speed pinion and gear of 3.5 and 8 inches respectively, which would be about the maximum reduction, and a final gear reduction of 7, the rear axle bevel gear reduction would be

$$\frac{3.5 \times 58.2}{8 \times 7} = 3.64 \quad \text{which is reasonable.}$$

8. Design of Change Speed Gears.

A 5 - 7 pitch stub tooth will be used. Referring to Fig. 10, let the number of teeth in each gear be denoted by the letter by which that gear is marked:

Let $A = 18$, number of teeth in low speed pinion.

Then $B = 18 \times 2.3$, or say 44, teeth in the low speed gear.

The reduction in intermediate is 2/3 of the low gear reduction. Therefore

$$\frac{D}{C} = \frac{2\,B}{3\,A} = \frac{2 \times 44}{3 \times 18} = 1.63$$

$$D = 1.63\,C$$

$$D + C = A + B = 18 + 44 = 62$$

$$1.63\,C + C = 62$$

$$C = 24$$

$$D = 38$$

The reduction in high is 1/2 that in low.

Therefore $\frac{F}{E} = \frac{B}{2A} = \frac{44}{2x18} = 1.22$

$$E + F = 62$$

$$2.22\,E = 62$$

$$E = 28$$

$$F = 34$$

9. Reverse Idlers.

The reasons for adoptigg the reversing mechanism shown in Fig. 10 have been discussed. At this stage the possibility of combining the reverse idler shaft and the power take-off was sggested, partly for sake of simplicity. This idea was adopted. In order for the shaft to clear the low gear, the minimum pitch diameter of the constantly meshed pinion was found to be 3.25. Using 17 teeth in pinion G, its pitch diameter becomes 3.4.

It is required to get the same reduction in reverse as in low gear, or a reduction of 2.34.

Then $\frac{D\,H}{E\,G} = 2.34$

$$H = \frac{2.34\,E\,G}{D} = \frac{2.34 \times 28 \times 17}{38} = 29.3 \text{ or say 30 teeth}$$

10. Power Take-Off.

The first plan was to have the power take-off shaft underneath as shown in Figs. 8 and 9. The difficulty of having an outlet on the gear-case below the oil level led to the idea of having this shaft above. Also, when combining with the reverse idler shaft it was thought advisable to have the reverse idlers above instead of below, where they would be totally immersed in oil which would cause a lot of unnecessary resistance to motion.

(a) Gear calculations. The speed of the power take-off shaft is to be 536 r. p. m. It is required to find the number of teeth in the gears I and J, Fig. 10.

$$I + J \quad E + H = 58 \text{ teeth.}$$

$$\frac{J}{I} = \frac{1,000}{536} = 1.87$$

$$2.87\ I = 58$$

$$I = 20 \text{ teeth}$$

$$J = 38 \quad "$$

11. Strength of Gear Teeth.

To determine the width of face of the different gears the Lewis Formula was used. For stub teeth, this formula reads:

$$f = \frac{W}{S\ z}$$

Where W is the tengential force in lbs.

s is the allowable stress in the material.

z is the constant depending upon the pitch and number ofteeth in the gear.

The value of S for carbon alloy steel teeth was obtained from Heldt, Vol. II, p.99.

The value of z for stub teeth was obtained from Heldt, Vol. II, Table II, p.99.

$$\text{Torque} = \frac{n\ l\ b^2 p}{192} \quad \ldots\ldots\ (1)$$ Heldt, Vol. II, p. 14.

Where n = number of cylinders

l = stroke*

b = bore*

p = mean effective pressure.

---

* For bore and stroke refer to page 83.

$$T = \frac{4 \times 5.5 \times 16 \times 75}{192} = 147 \text{ lbs. feet.}$$

(a) <u>Low gear</u>:

$$w = \frac{12 \times 147 \times 2}{3.6} = 980 \text{ lbs.}$$

$$\text{Pitch line velocity} = \frac{1{,}000\pi \times 3.6}{12} = 944 \text{ ft. per min.}$$

$$S = 11{,}000 \text{ lbs. per square inch.}$$

$$z = .086$$

$$f = \frac{980}{11{,}000 \times .086} = 1.04''$$

Add 3/16 inch for chamfer and inaccurate meshing.

Let width of face of low gears = 1 1/4"

(b) <u>Intermediate Gears</u>.

$$w = \frac{12 \times 147 \times 2}{4.8} = 735 \text{ lbs.}$$

$$\text{Pitch line velocity} = \frac{1{,}000\pi \times 4.8}{12} = 1{,}260 \text{ ft. per min.}$$

$$S = 9{,}000$$

$$z = .095$$

$$f = \frac{735}{9{,}000 \times .095} + .187 = 1.047''$$

(c) <u>High Gear</u>.

$$w = \frac{12 \times 147 \times 2}{5.6} = 630 \text{ lbs.}$$

$$\text{Pitch line velocity} = \frac{1{,}000\pi \times 5.6}{12} = 1470 \text{ ft. per min.}$$

$$S = 7{,}000$$

$$z = .098$$

$$f = \frac{630}{7{,}000 \times .098} + .187 = 1.107''$$

It was decided to use all change speed gears of $1\frac{1}{4}$ inch face.

12. Calculations of Shafts.

Shafts must be calculated both in torsion and deflection. The maximum allowable deflection is taken at .003". A shearing stress of 5,000 lbs. per sq. inch is allowed.

(a) Transmission Shaft.

For torsion in circular shafts.

$$d = \left(\frac{5.1\ T}{S}\right)^{1/3}$$

$$d \quad \left(\frac{5.1 \times 147 \times 12}{5{,}000}\right)^{1/3} = 1.22$$

The greates deflection will occur when in intermediate, as these gears are almost at the center of the shaft.

The load upon the shaft is greater than the tangential force. The load, $P = \dfrac{W}{\cos 25^{\circ}}$

In intermediate, $P = \dfrac{735}{.906} = 810$ lbs.

The deflection for a circular shaft with a concentrated load in the center is

$$y = \frac{P\ l^3}{48\ E\ I} \qquad I - .049\ d^4$$

$$d^4 = \frac{P\ l^3}{.049 \times 48 \times E\ y}$$

$$d = \left(\frac{810 \times 11.5^3}{.049 \times 48 \times 30{,}000{,}000 \times .003}\right)^{\frac{1}{4}} = 1.6"$$

Using a S. A. E. standard y B spline on transmission shaft, the outside diameter,

$$D = \frac{d}{.85} = \frac{1.6}{.85} = 1.88"$$

Let outside diameter of transmission shaft = 2".

(b) Countershaft.

The greatest torsion in the countershaft occurs when in low or reverse. The torque in low = $\frac{147 \times 44}{18}$ = 360 lbs feet.

$$d \quad \left(\frac{5.1 \times 360 \times 12}{5,000}\right)^{1/3} \quad 1.64$$

As this shaft is only 8.3 inches long, deflection will not need to be considered.

Let diameter of countershaft = 1 $\frac{3}{4}$"

(c) Power Take - Off and Reverse Idler Shaft.

When in reverse this shaft is subjected to a deflection by a force $P = \frac{630 \times 30 \times 38}{.906 \times 28 \times 17} = 1660$ lbs.

The shaft is 11$\frac{1}{4}$" long, and this load is practically at the center,

$$d \quad \left(\frac{1660\ (11.25)^3}{.049 \times 48 \times 30,000,000 \times .003}\right)^{\frac{1}{4}} \quad 1.82"$$

As this load occurs only when in reverse, it will be safe to use a 1$\frac{3}{4}$" shaft.

13. Bearing Loads.

In low gear $P = \frac{980}{.906} = 1,080$ lbs.

This load is practically all carried on the front bearing of the countershaft, and represents the heaviest bearing load in this part of the transmission. At the driving end of the countershaft it is not permissible to reduce the size of the shaft to any extent. In order to use the same size bearings at both ends, a bearing of sufficient size and of approximately 1080 lbs. capacity should be selected. Bearing No. 1208 from New Departure data sheets comes nearest to this.

Further bearing calculations will not be given here, but a list of the bearings used will be given separately.

14. Belt Drive.

It was decided to place the belt pulley on the right side and out far enough to clear the front wheel. The belt pulley is engaged by means of the same jaw clutch as the power-take-off; see Fig. 12 on page 116.

(a) Belt speed. A belt speed of 3,000 ft. per min. was chosen, according to recommendations of the S. A. E. for this size of machine.

(b) R. P. M. of Belt Pulley.

Using a pulley of 14 inches diameter, the speed of the belt pulley should be $\frac{3,000 \times 12}{14 \pi} = 820$ r. p. m.

(c) Bevel Gears. Referring to Fig. 10, page103, if gear K has 24 teeth, the number of teeth in gear L is

$$\frac{1,000 \times 24}{820} = 28$$

The belt pulley will extend further out than the outer edge of the driver, but the shaft will not extend out that far.

The belt pulley may easily be removed when doing field work if desired, and a collar put on in its place to keep dirt out of the bearing.

15. Final Drive.

It has been decided to use internal master gears for the final drive. A reduction of 7 is desired.

Let the pitch of the gears be 3 - 4, using stub teeth.

Diameter of drivers is 46 inches.

Let number of teeth in pinion be 12, then the pitch

diameter of the pinion $= \frac{12}{3} = 4''$

Number of teeth in gear, $7 \times 12 = 84$.

Pitch diameter of gear, $\frac{84}{3} = 28''$

Then height of rear axle $= 23 + 14 - 2 = 35''$

16. Rear Axle Bevel Gears and Differential.

A bevel gear reduction of 3.5 has been computed to give the desired speeds; see page .

Using straight bevel gears of 5 diametral pitch and 16 teeth in the pinion, the number of teeth in the gear

$16 \times 3.5 = 56$

Max. pitch diameter of pinion $\frac{16}{5}$ 3.2"

Max. " " " gear $\frac{56}{5}$ 11.2

17. Gear Carrier.

The rear axle, shown in Fig. 13 is of the banjo type, but the gear carrier is so designed as to form a unit which may be removed, inclusive of the usual rear cover which forms.

part of the gear carrier and fits in from the front. The reason for this design is that this unit must carry the power take-off, which is put on the rear axle in order that the jars and jolts may be taken up by the most rigid part of the tractor.

The power take-off is then carried from the change speed gear box back to the rear axle by a shaft paralled with the drive shaft. The differential has been so designed as to clear this shaft.

18. Universal Joints.

Three universal joints will be required, which might be of the fiber type, as no appreciable angle is likely to occur. One universal joint is required between the clutch and the transmission shaft, another between the countershaft and the bevel pinion, and the third on the power take-off shaft in front of the rear axle.

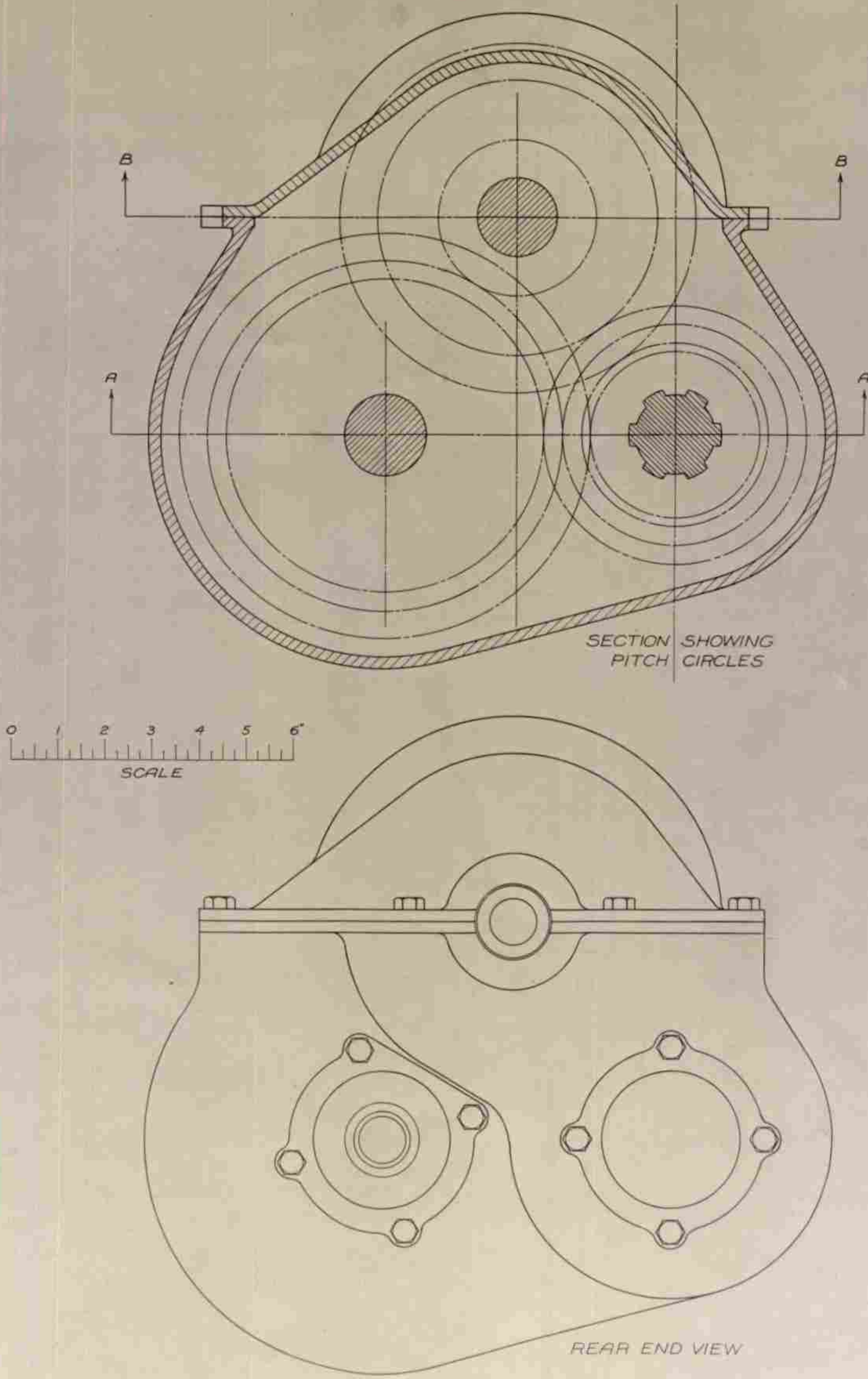
## 19. Bearings.

### New Departure Ball Bearings Used in Transmission.

| | |
|---|---|
| Transmission shaft, front. . . . . . . . . . . . . . . . | No. 1207 |
| " " center . . . . . . . . . . . . . . | 210 |
| " " rear . . . . . . . . . . . . . . . | 1208 |
| Countershaft, front and rear . . . . . . . . . . . . | 1208 |
| Power take-off and idler shaft, front and rear . . . | 1208 |
| Pulley shaft, inside . . . . . . . . . . . . . . . . | 208 |
| " " outside. . . . . . . . . . . . . . . . . | 1208 |
| Bevel pinion bearing, outside. . . . . . . . . . . . | 308 |
| " " " inside . . . . . . . . . . . . | 1306 |
| Differential shaft bearings, inside. . . . . . . . . | 1214 |
| " " " outside . . . . . . . . | 1210 |

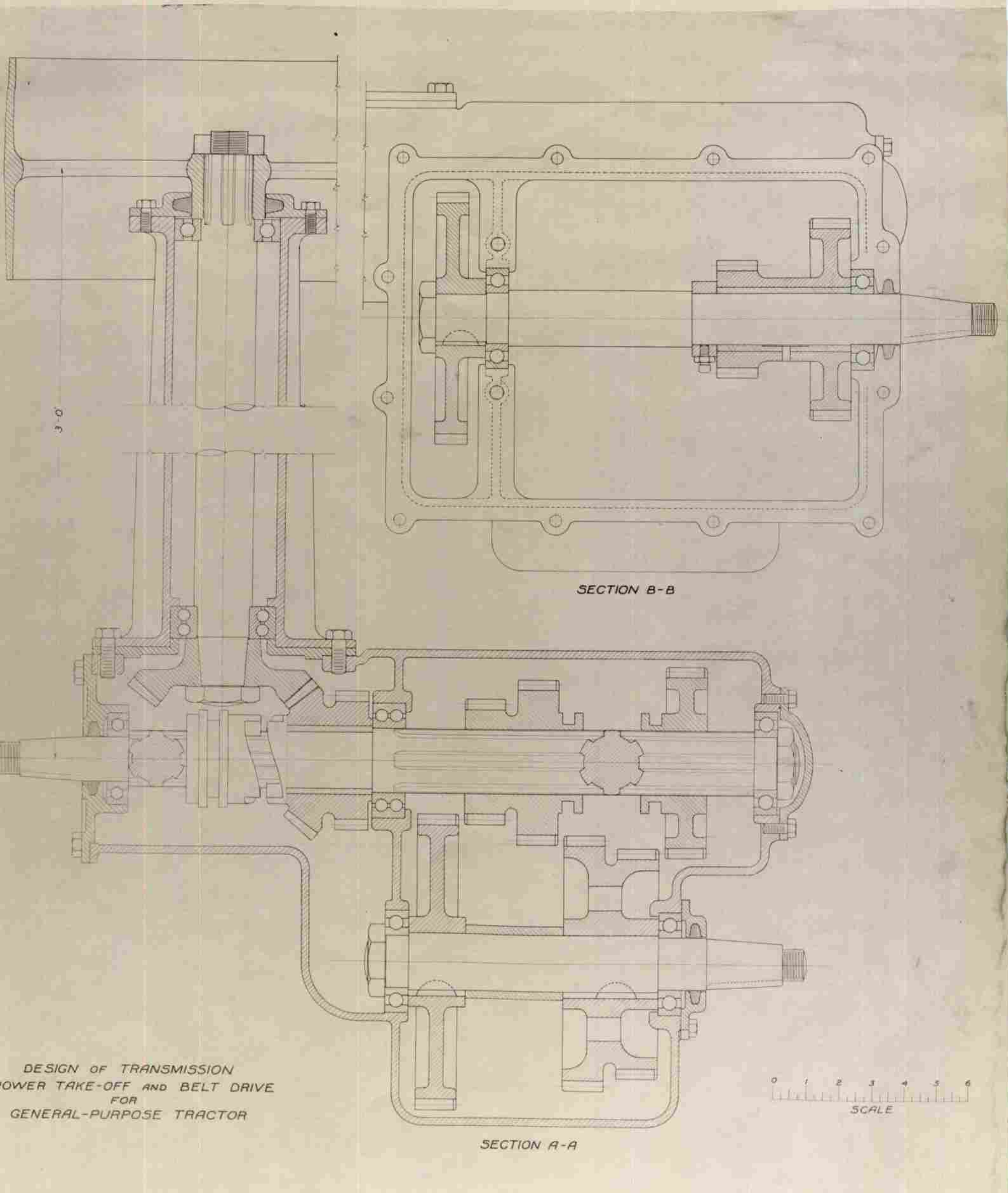
### Timken bearings used in drive wheels.

| | |
|---|---|
| Inner. . . . . . . . . . . . . . . . . . . . . . . . | 537 E - 532 |
| Outer. . . . . . . . . . . . . . . . . . . . . . . . | 440 - 432 |




CHANGE SPEED GEAR CASE

Fig. 11




DESIGN OF TRANSMISSION
POWER TAKE-OFF AND BELT DRIVE
FOR
GENERAL-PURPOSE TRACTOR

Fig. 12

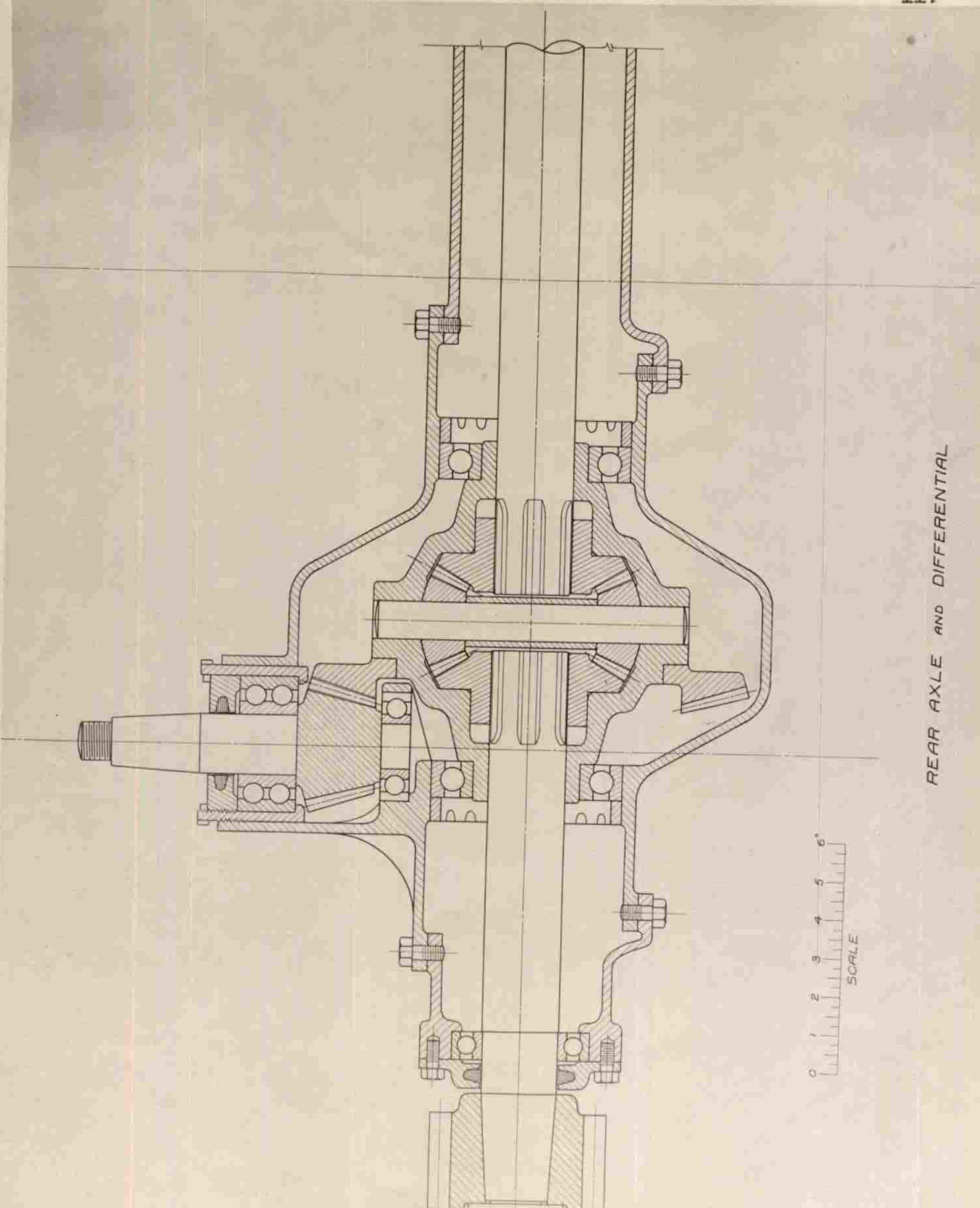



Fig. 13

X. Friction Clutch.

The design of a clutch has not been gone into in this work. The essential feature of a clutch for this assembly is that the clutch shaft be as short as possible. The engine and the transmission must be quite close together in order to leave sufficient clearance between the belt pulley and the drive wheel.

XI. Front Axle.

The matter of obtaining clearance under the front axle has been given considerable thought. The most natural way at first seemed to be to build an arched axle, pivoted at the top of the arch. This pivot would need to be about 30 inches above the ground, which would have the effect of exaggerating the tendency for the front end to swigg sideways when one front wheel drops into a low place. This would make the steering considerably more difficult than when the front axle is pivoted at a height of approximately the radius of the wheels, which is the usual design.

In order to retain the arch for clearance and yet have the effect of the low pivot, the link connected front axle sho n in Fig. 14 was suggested. The upper end of each link is connected to the frame, while the lower end is pinned to the front axle. Fig. 14 shows the effect of a 12 inch drop of one of the front wheels upon the front end of the tractor. As designed, the link connected front axle gives the tractor

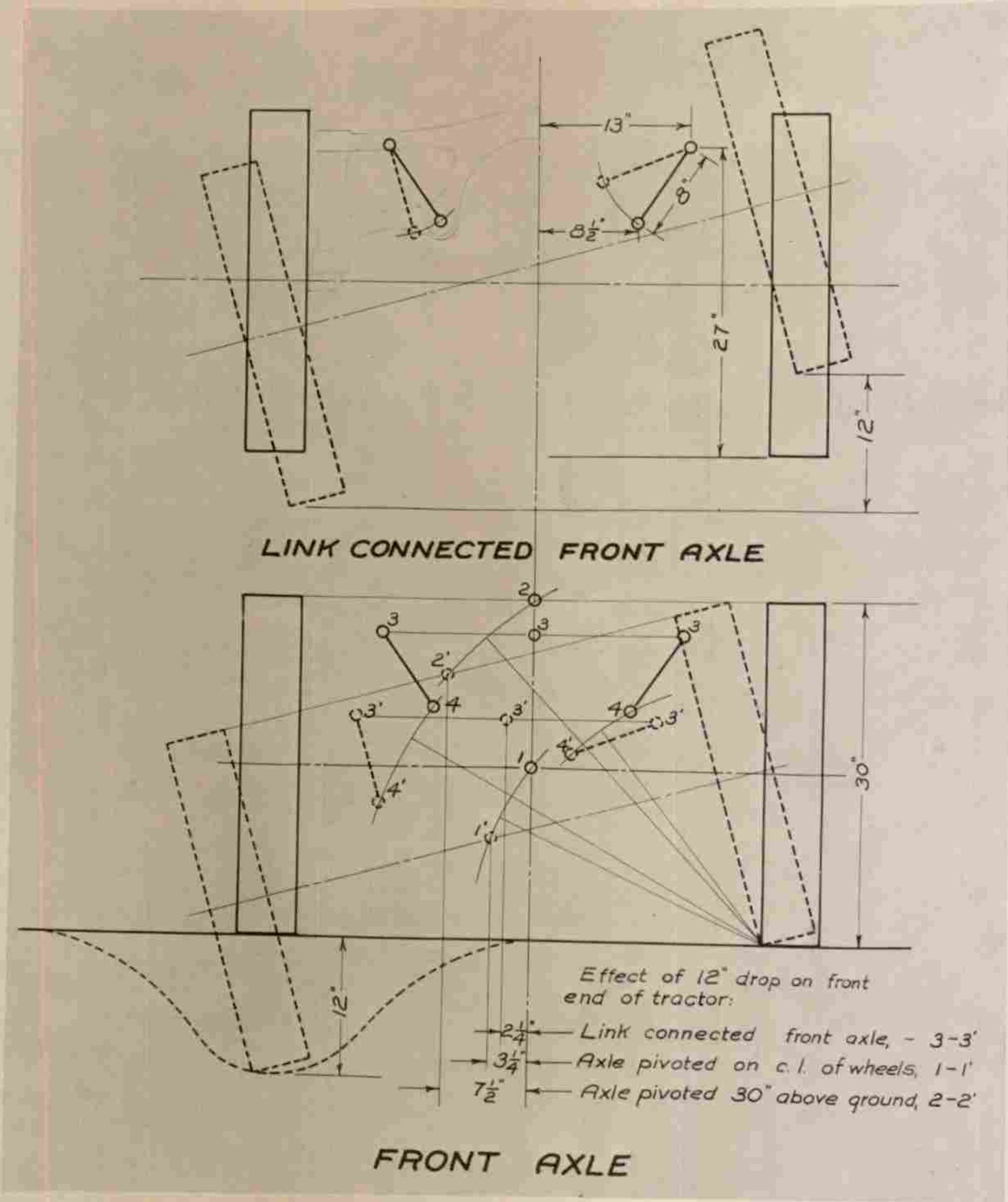

13"
8"
8½"
27"
12"
LINK CONNECTED FRONT AXLE
30"
12"
Effect of 12" drop on front end of tractor:
2¼" Link connected front axle, - 3-3'
3¼" Axle pivoted on c. l. of wheels, 1-1'
7½" Axle pivoted 30" above ground, 2-2'
FRONT AXLE

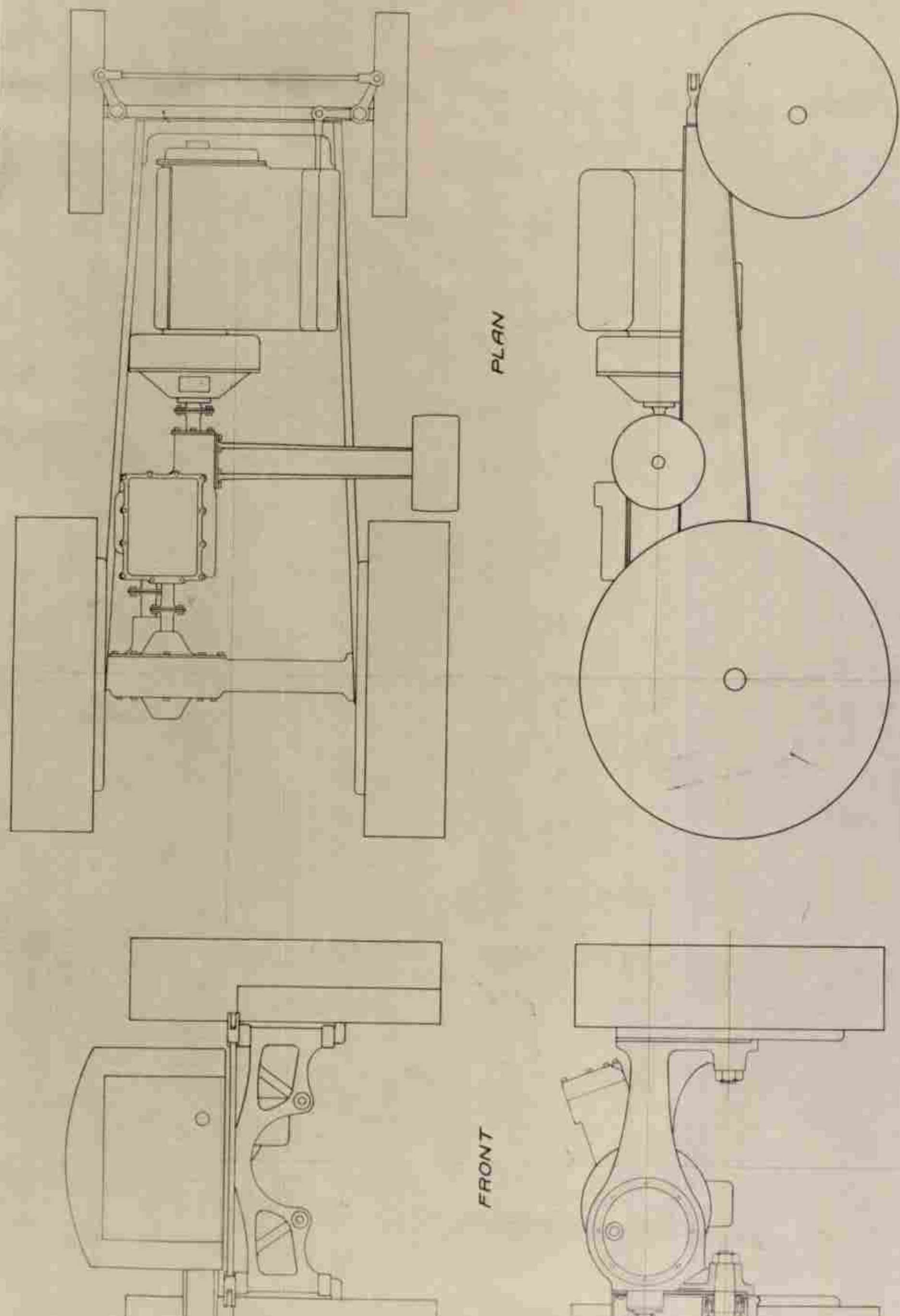
Fig. 14

the least side motion of the three arrangements.

Beyond the kinematics of the problem, the design of the front axle has not been gone into in this work.

## XII. Frame.

In order to keep down weight, a light frame should be used. Although the actual design of the frame has not been undertaken, it is thought that a rather light pressed steel frame might be used. Fig. 15 shows a method of attaching the rear axle to the frame in order to give it stiffness. The circular section of therear axle makesiit well adapted to taking up torsion. Two cross members would also add to the stiffness of the frame.




PROPOSED GENERAL-PURPOSE TRACTOR ASSEMBLY

Fig. 15

## XIII. Specifications.

| | |
|---|---|
| Belt horsepower, (rated) . . . . . . . . . . . . . . . | 18 |
| Drawbar horsepower, (rated) . . . . . . . . . . . . . | 9 |
| Overload capacity, per cent . . . . . . . . . . . . . | 22 |
| Cylinders, number . . . . . . . . . . . . . . . . . . | 4 |
| Cylinder bore, inches . . . . . . . . . . . . . . . . | 4 |
| Piston stroke, inches . . . . . . . . . . . . . . . . | $5\frac{1}{2}$ |
| Belt speed, feet per minute . . . . . . . . . . . . . | 3,000 |
| Belt pulley; diameter, inches . . . . . . . . . . . . | 14 |
| R. P. M. . . . . . . . . . . . . . . . . . . | 860 |
| Face, inches . . . . . . . . . . . . . . | 7 |
| Power take-off shaft, r. p. m. . . . . . . . . . . . | 530 |
| Forward speeds, miles per hour . . . . . . . . | 2, 3 and 4 |
| Reverse speed, miles per hour . . . . . . . . . . . | 2 |
| Drive wheels; Diameter, inches . . . . . . . . . . . | 46 |
| Face, inches. . . . . . . . . . . . . . | 12 |
| Tread, o. c., inches . . . . . . . . . | 52 |
| Front wheels; diameter, inches. . . . . . . . . . . . | 30 |
| Face, inches. . . . . . . . . . . . . . | 5 |
| Tread, o. c., inches . . . . . . . . . | 45 |
| Wheel base, inches . . . . . . . . . . . . . . . . . | 82 |
| Clearance, inches . . . . . . . . . . . . . . . . . . | 28 |

# SUMMARY.

## I. The Farm Power Situation.

1. Annual cost of farm power in the U. S. about $3,000,000,000.00.
2. This represents about 20% of the cost of production of agricultural products.
3. Field work consumes approximately half of this power.
4. Animal power was used to do 88.2% of the field work in 1923.
5. Mechanical power, where used, costs only about half as much as animal power per H. P. hr.
6. Tractors are not used for inter-tillage.
7. Almost half the crop acreage in the U. S. is inter-tilled.
8. The proposed solution of this problem is the general-purpose tractor.

## II. The Design of a General-Purpose Tractor.

The main features of the proposed general-purpose tractor are:

1. Conventional four wheel type with rear wheel drive.
2. Three-row cultivator attachment with shovels set well ahead for convenience in guiding.
3. Engine offset 6" to left of center line of the tractor to obtain clearance, and tilted 20° from horizontal to improve accessibility, lubrication and to preserve balance.
4. Unit assembly of such parts as engine and transmission.

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